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Centrifuge modelling of large diameter pile in sand subject to lateral loading

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Preface

This Technical Report describes physical tests on lateral loaded large diameter piles carried out in the geotechnical centrifuge at Department of Civil Engineering at Technical University of Denmark, (DTU Byg).
The report includes a description of the centrifuge facilities at DTU Byg and the equipment applied in the pile tests.
The table of content is given on the next page.
A CD is included which contains additional documents and test data.

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Randers, November 2011

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Appendix A Mini penetrometer, documents submitted by ISMES.

Appendix B Results from lateral load tests.

Appendix C Data report by Rasmus Klinkvort: *Tværbelastning af monopæl. Geoteknisk datarapport*.

Appendix D Sieve analyses on Fontainebleau sand.

Appendix E Pycnometer analyses on Fontainebleau sand.

Appendix F Void ratio analyses on Fontainebleau sand.

Appendix G Triaxial tests on Fontainebleau sand.

Included on CD:

Calculation of centre of gravity for penetrometer frame

Calibration sheets

Data sheet 1 - Circular container

Data sheet 2 - LVDT Beam

Data sheet 3 - Control weights

Determination of centre of gravity for loading frame

Original documentation for design of penetrometer frame

Original documentation for rebuild of penetrometer frame

Sheets with preparation of sand sample

Abstract

Large-diameter (4 to 6 m) rigid monopiles are often used as foundations for offshore wind turbines. The monopiles are subjected to large horizontal forces and overturning moments and they are traditionally designed based on the p-y curve method. The p-y curves recommended in offshore design regulations are developed for long flexible piles with diameters up to approximately 2.0 m and are based on a very limited number of tests. Hence, the method has not been validated for rigid piles with diameters of 4 to 6 m.

The primary issues concerning the validity of the standard p-y curves for large diameter rigid piles are:

- The initial stiffness of the curves and description of the static behaviour, including ultimate bearing capacity.
- The behaviour with respect to cyclic loading both stiffness degradation and ultimate bearing capacity.

The aim of the present research is to investigate the static and cyclic behaviour of large diameter rigid piles in dry sand by use of physical modelling.

The physical modelling has been carried out at Department of Civil Engineering at the Danish Technical University (DTU.BYG), in the period from 2005 to 2009.

The main centrifuge facilities, and especially the equipment for lateral load tests were at the start of the research in 2005 outdated and a major part of the work with the geotechnical centrifuge included renovation and upgrading of the facilities.

The research with respect to testing of large diameter piles included:

- Construction of equipment for preparation of sand samples.
- Testing of preparation method.
- Modification of available loading equipment for lateral load tests.
- Calibration of equipment.
- Completion of a series of lateral load tests.

The lateral load tests carried out represent prototype piles with a diameter of 1, 2 and 3 m with embedment lengths of 6, 8 and 10 times the diameter. The tests have been carried out with a load eccentricity of 2.5 m to 6.5 m above the sand surface.

The present report includes a description of the centrifuge facilities, applied test procedure and equipment along with presentation of the obtained results.

1. Geotechnical centrifuge

The geotechnical section in the Department of Civil Engineering at the Technical University of Denmark (DTU Byg) operates a geotechnical beam centrifuge. The centrifuge was built in 1976 and has been upgraded over the years, latest with onboard data acquisition and control systems. The capabilities of the centrifuge at DTU Byg make it possible to obtain a scale factor of 75-85 in the centrifuge tests which equals a soil volume in prototype scale of ø40m and a depth of 40 m.

1.1 Physical details

The centrifuge at DTU Byg is a standard beam centrifuge, based on a symmetrical layout around the rotational axis, with one swing cradle for the test setup and a second for the counter weight. The centrifuge is shown in Figure 1.1. The centrifuge arm is 1.7 m from rotational axis to reference hinge. The swing cradle (U-shaped yoke) is 0.93 m high, hence platform radius is 2.63 m. A maximum of 450 kg soil sample and test setup can be applied. The capacity of the centrifuge is 100 g-ton, and it can provide a gravitational acceleration of 75-85 g (Fuglsang, 1977).

Figure 1.1 Centrifuge at DTU Byg. Left: Swing cradle for test setup. Right: Swing cradle for counter weights.

Two sample containers, a circular and a rectangular, are available with the properties listed below in Table 1.1. The listed prototype soil volume is based on a gravity scale of 80. One side of the rectangular container is made of Plexiglass which makes it possible to visually monitor the model. The centrifuge has been used for testing sand, clay and limestone samples. Sand samples can be prepared by use of sand rain or spot pouring methods, whereas clay samples either are reconstituted intact clay or kaolin clay, both consolidated according to planned tests by preload or in the centrifuge

Table 1.1 Properties for centrifuge containers at DTU Byg.

	Circular container	Prototype volume
Diameter	53 cm	42 m
Height	49 cm	39 m
	Box container	Prototype volume
Length	70 cm	56 m
Width	50 cm	40 m
Height	70 cm	56 m

The centrifuge was build in 1976, and had a major upgrade in 1998 sponsored by the Corrit Foundation. The laboratory housing the centrifuge and the centrifuge itself has in the period from 2005 to 2009 been renovated and upgraded.
The upgrade in 1998 primary consisted of a video surveillance system for the centrifuge, making it possible with in-flight monitoring of the tests, and new computers for the data logging, video surveillance and image analysis.
The primary renovation and upgrade in 2005-2009 included:

- Renovation of the main power supply to the laboratory building.
- Renovation of the hydraulic engine driving the centrifuge.
- The laboratory building has been renovated due to cracks in wall supporting the main crane.
- Replacement of the data logging setup and test control system. Application of flight computer with wireless LAN access. Introduction of LabVIEW programming language for test control and data acquisition.
- New revolution indicator.

1.2 Centrifuge controls

The centrifuge control and data acquisition system is illustrated in Figure 1.2. The main feature is execution of the tests by use of a flight pc located on the centrifuge. The flight pc is remotely controlled from the control room.

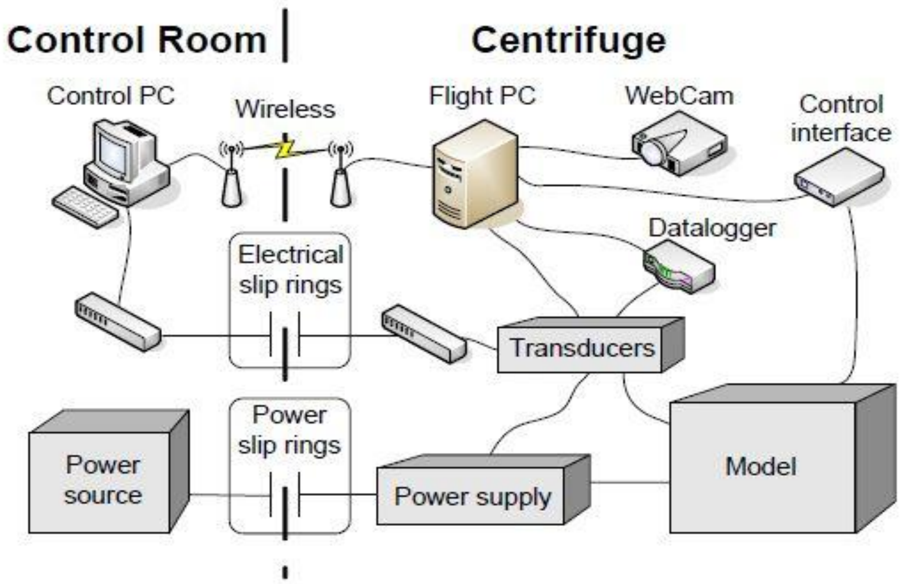
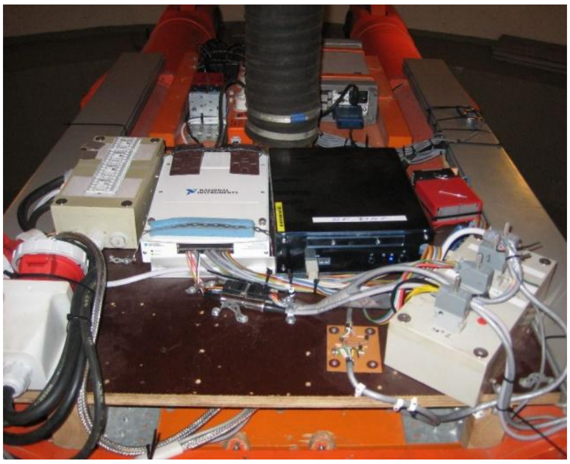


Figure 1.2 **Schematic view of centrifuge control and data acquisition system..**

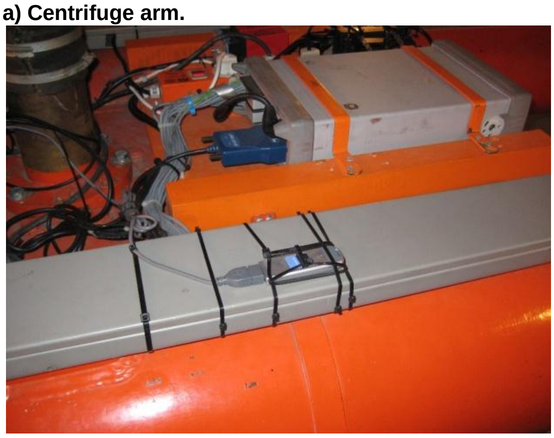
Specification of centrifuge control and data acquisition components:

- Control pc: Standard stationary pc with Intel Pentium 3.2 GHz processor and 2GB ram & 80 GB HD.
- Electrical rotary joint with 3 sets of electrical slip rings (low voltage, 5/10/24 VDC), each with 20 connections, and one set of power slip rings, with 3 phases and zero & ground (220/380 VAC).
- Wireless access: Standard wireless access point (Proxim ORiNOCO access point).
- Flight pc: Mini-ITX with Intel Atom 300 1.6 GHz processor and 2GB ram & 80 GB HD. LAN access is ensured by use of a Linksys wireless usb network adapter. Test surveillance is carried out by use of a standard webcam (Creative, Live Cam Notebook).
- Data acquisition and test controls is handled by use of a National Instrument multifunctional DAQ connected by USB to the flight pc (NI USB-6221). The DAQ has 16 analog inputs, 2 analog outputs and 24 digital I/O
- The data logger present on the centrifuge arm is of the type HP34970A fitted with two 16 channels multiplexer of the type HP34902A. The data logger is wired to the flight pc by use of a GPIB controller for USB (NI GPIB-USB-HS). The data logger is capable of logging the electrical power supply (low voltage), revolution indicator and 20 transducer plugs (6 pin Amphenol 97 plug).

a) Centrifuge arm.



b) Flight PC and DAQ (NI USB-6221).



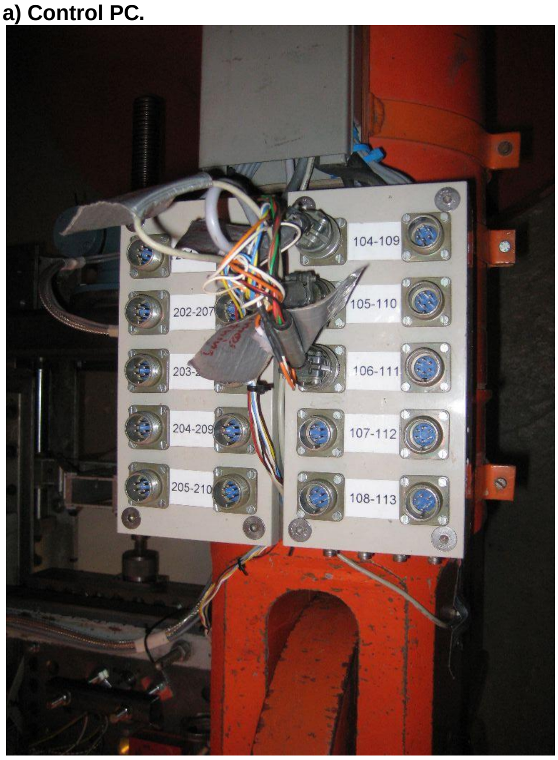
c) Wireless network adapter and data logger.

d) Power supply and transducer plugs.

Figure 1.3 Photos of centrifuge part 1 of 2.

a) Control PC.

b) Data logger.



c) Transducer plugs (6 pin Amphenol 97).

d) Main centrifuge controls.

Figure 1.4 Photos of centrifuge part 2 of 2.

1.3 Application of centrifuge in research

The centrifuge has over the years been used for testing various geotechnical issues, and some of these issues are:

- Behaviour of suction anchor in sand – installation and determination of ultimate resistance. (Foged, 2000).
- Negative skin friction on pile and pile groups in clay. (Christensen & Mortensen, 1997).
- Tension piles in clay. (Larsen & Nielsen, 1991).
- Cone penetration tests in sand and clay with measurement of pore pressure, tip resistance and skin friction. (Petersen & Molnit, 1992)
- Vertical bearing capacity of thin walled profiles. (Meier & Møller, 2004).
- Active earth pressure on sheet pile walls in sand. (Schultz & Larsen, 2003; Krogsbøll & Fuglsang, 2006).

- Group effects for laterally loaded piles in sand and clay. (Haahr, 1989; Brødbæk, 2000).
- Stresses in concrete pipes – pipes placed in soil with applied surface load. (Hegnsted & Hansen, 1978).
- Laterally loaded pile in sand – large diameter piles exposed to static and cyclic lateral loads. Current research and Klinkvort (2009a).

2. Centrifuge testing

2.1 Test sequence

A series of lateral load test is carried out to investigate the static and cyclic behaviour of large diameter rigid piles in dry sand. Following steps and supplementary centrifuge tests have been included in the physical tests:

- Preparation of sand sample
- Classification and triaxial tests on applied Fontainebleau sand.
- In-flight testing of prepared sand sample by use cone penetration tests.
- Consolidation of soil sample due to start-up of centrifuge from stress field at 1×g to stress field at N×g. The model test will be carried out at N×g.
- Lateral load test.
- Calibration of laboratory equipment.

2.2 Fontainebleau sand

Fine Fontainebleau Sand is used in laboratory tests by the geotechnical group at DTU Byg. The tests include, but are not limited to, classification, triaxial and model tests.

The Fontainebleau Sand is a natural uniform silica sand from the region of Etampes south of Paris in France. The silica sand consists of fine rounded particles, with a particle size is in the range of 0.06 mm to 0.50 mm, and an average size of approximately 0.2 mm.

Classification and triaxial tests has been carried out on the batch of Fontainebleau sand used in the present series of tests related to centrifuge modelling of large diameter pile in sand subject to lateral loads.

Classification tests were carried out on 4 bag samples in connection with a special course at DTU Byg (Klinkvort & Hansen 2007), while triaxial tests for this project were carried out on one large bag sample by Ph.D. student Rasmus Klinkvort in 2010.

The available tests consist of:

- 4 sieve test.
- 8 pycnometer tests.
- 8 void ratio tests, 4 on minimum void ratio and 4 on maximum void ratio.
- 6 triaxial tests

The findings from the tests are summarized in the following two sections and the data sheets are included as Appendix D-G.

2.2.1 Classification tests

The main findings from the following classification tests are summarized in Table 2.1.

- 4 sieve test.
- 8 pycnometer tests.
- 8 void ratio tests, 4 on minimum void ratio and 4 on maximum void ratio.

Data sheets for the three test types given in Klinkvort & Hansen (2007), and are included as Appendix D, E and F respectively.

Table 2.1 Summary of classification tests.

Average grain size	d_{50}	0.18
Uniformity index	U	1.6
Specific gravity of particles	d_s	2.646
Minimum void ratio	e_{min}	0.548
Maximum void ratio	e_{max}	0.859

2.2.2 Triaxial tests

A series of triaxial tests on dry Fontainebleau sand was carried out by Ph.D. student Rasmus Klinkvort in the spring 2010.

The tests were carried out with a void ratio of 0.599 (relative density of 0.837), equal to a density of 1.665 g/cm^3. Following stress levels were applied in the tests:

- 30 kPa, one test
- 60 kPa, one test
- 150 kPa, two tests
- 300 kPa, two tests

The results for each test are included in Appendix G, while the the stress path applied to the samples for all the testes are shown in Figure 2.1.

A relation between change of friction angle and change in void ratio has in unpublished tests been determined as:

$$\Delta \tan(\varphi) = -1.75\,\Delta e$$

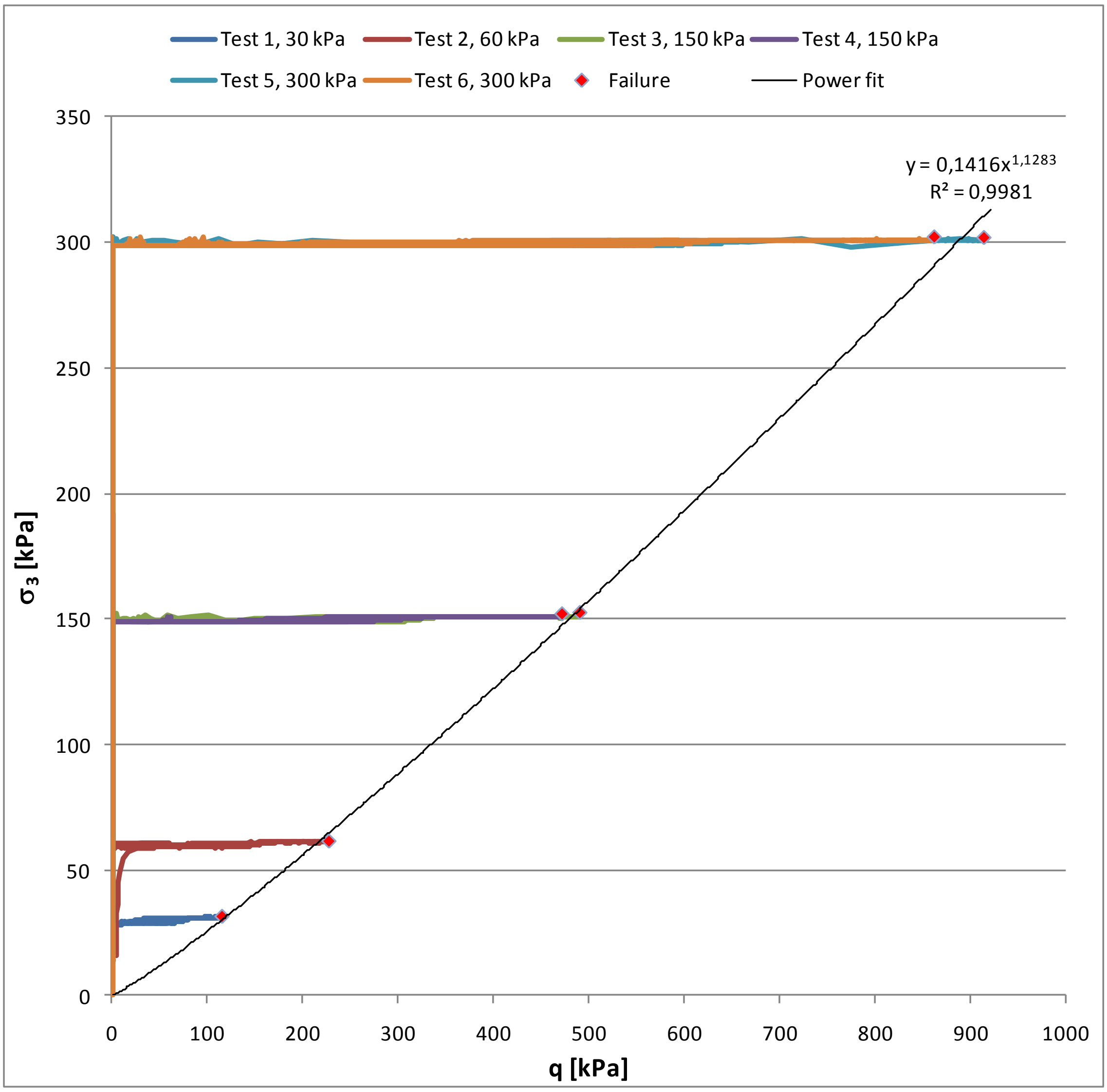


Figure 2.1 **Stress path applied in triaxial tests on Fontainebleau sand.**

2.3 Preparation of sand sample

2.3.1 Introduction to preparation of sample

A spot pouring hopper (SPH) has been build at DTU Byg for preparing sand samples, cf. Meier & Møller (2004). The equipment was based on Chen et al. (1998), which in addition to description of equipment also describes the findings of more than 40 preparation tests. The SPH setup from 2004 consisted of (from the top):

- Funnel.
- Flexible tube, length of 52 cm and internal diameter of 20 mm.
- Rigid tube, length of 101 cm and internal diameter of 16 mm.
- Changeable nozzle with an internal diameter in the range of 10 to 16 mm.

An elevated container for storage of sand was in 2005 added to the existing SPH and a series of preparation tests were carried out.

The basics of the SPH is that the density of a prepared sample is controlled by variation of drop height and flow rate (muzzle). Decreasing flow rate (muzzle diameter) and increasing drop

height increases the density, where the major influence is from changes in flow. (Chen et al. 1998 and Zhao et al. 2006).
The muzzle is by the user moved back and forth over the container. The pattern used, also called traveling-loop, is roughly split in two types (see Figure 2.2). The influence on the density from the applied pattern is expected to be very small, less than 1% according to Chen et al. (1998).

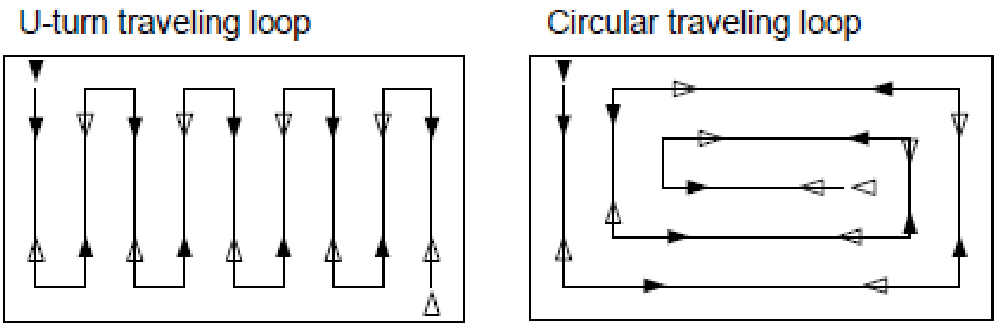


Figure 2.2 Travelling loops.

It is noted by Zhao et al. (2006) that the shape of the sample container has an influence on the obtained density, and thus makes it necessary to perform calibration/initial tests on a container similar to the container used in the tests.
The procedure applied to prepare the sample will influence the obtained density and repeatability, hence a degree of user dependency is expected with the use of the SPH.
The preparation tests with the existing setup described above showed some impractical issues with the design, and it was revised based on Zhao et al. (2006).
The revised SPH setup is outlined in Figure 2.3 and consists of:

- Elevated container for storage of the sand. The elevation can be adjusted.
- Valve that controls the sand flow.
- Flexible tube.
- Muzzle with guide. The muzzle controls flow rate of the sand into the sample container..

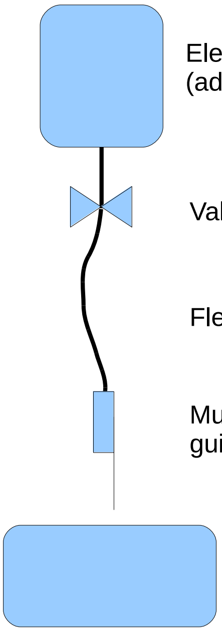


Figure 2.3 Outline of spot pouring hopper (SPH).

2.3.2 Equipment

The present equipment at DTU Byg has following properties:

- Container with a volume of 200 litres for storage of sand.
- ø100 mm valve that controls the sand flow from the storage container.
- Flexible tube with a length of 100 cm. The flexible tube is connected to a funnel located below the control valve.
- Muzzle consisting of orifice plate and sieves.
- Drop height of up to 70 cm. A simple wire guide is used to verify the drop height.

The equipment is shown on the pictures below, Figure 2.4 to Figure 2.7.

Components of the muzzle are shown in Figure 2.8, where as the assembled muzzled is sketched in Figure 2.9. The main parts of the muzzle are the orifice plate and the sieves. The orifice plate has a central hole, which directly controls the flow rate through the muzzle, i.e. increasing diameter gives increasing rate. The main function of the sieves is to smooth the flow to avoid a concentrated jet.

Figure 2.4 **Container with a volume of 200 litres.**

Figure 2.5 **SPH setup, ready for preparation of sample.**

Figure 2.6 **Control valve and funnel with flexible tube.**

Figure 2.7 **Muzzle with wire guide.**

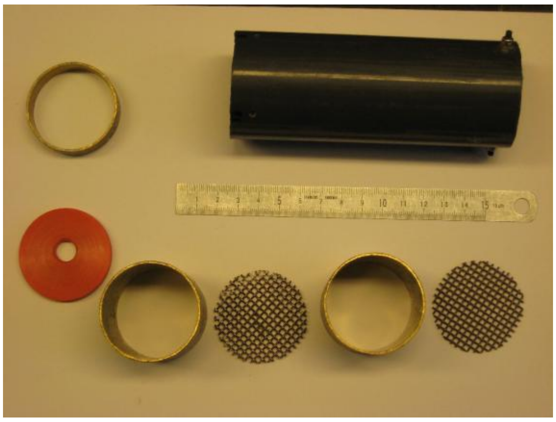


Figure 2.8 Muzzle components.

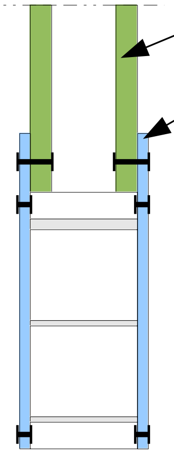


Figure 2.9 Outline of assembled muzzle.

2.3.3 Procedure for preparation of sand sample

Following procedure is applied for preparation of sample with the spot pourer:

1. Determine the mass of the container.
2. Elevate the storage container and assemble the SPH.
3. Fill the sample container following a chosen pattern (use same pattern sequence during process). Continuously adjusting the elevation of storage container to ensure a constant drop height. Fill to at least 0.5 cm above needed sample surface.
4. Use a guide to carefully adjust surface of sand and remove excess material.
5. Determine the mass of the container and sand sample. Calculate average void ratio / density to check validity of prepared sample.

Requirements:

- Calibrated load cell.
- Dimensions of container.
- Void ratio in loosest and densest state and grain density of sand (used to calculate average void ratio of sample and relative density).

Notes:

- Experience shows that the shape and dimensions of the sample container has an influence on the density cf. Zhao et al. (2006).
- The method is user dependent.
- Flow rate and drop height is used to variate obtained density, where the greatest influence is from the flow rate, with lower flow rate giving higher density.

2.3.4 Preparation of samples for centrifuge tests

Data from preparation of 37 sand samples used in the physical tests reported in the present report are summarized in Table 2.2 with notes listed in Table 2.3. Data sheets from the preparations are included as pdf-files on the CD enclosed the present report.

Table 2.2 Summary of preparation of sand samples.

Date	User	Fall Height	Nozzle*	Sieve**	Orifice plate**	Sample height	Free height	Density	Void ratio, e	Relative void ratio, Id	Note
[-]	[-]	[cm]	[mm]	[mm]	[mm]	[cm]	[cm]	[kg/m^3]	[-]	[-]	[-]
01-02-2006	CTL	10	16	-	-	29,3	16,2	1513,2	0,749	0,355	1
07-02-2006	CTL	10	16	-	-	29,5	16,0	1466,4	0,804	0,176	2
17-03-2006	CTL	10	16	-	-	29,5	16,0	1314,3	1,013	-0,496	2
07-09-2006	CTL	10	15	-	-	29,5	16,0	1513,3	0,748	0,355	2
10-01-2007	CTL	10	16	-	-	28,0	17,5	1538,0	0,720	0,446	2
29-10-2007	CTL	10	-	2	24	30,7	19,0	1547,4	0,71	0,479	3
06-11-2007	CTL	10	-	2	24	30,7	19,0	1520,3	0,74	0,381	4
06-02-2008	CTL	10	-	2	12	30,7	19,0	1516	0,745	0,365	4
07-02-2008 a)	CTL	10	-	2	12	30,7	19,0	1521,8	0,739	0,387	4
07-02-2008 b)	CTL	10	-	2	8	30,7	19,0	1640,8	0,613	0,792	4
16-02-2008	CTL	10	-	2	10	30,7	19,0	1587,3	0,667	0,617	5
20-02-2008	CTL	50	-	2	10	30,7	19,0	1614,6	0,639	0,708	4
03-03-2008	CTL	50	-	2	10	48,7	1,0	1639,8	0,614	0,789	4
06-03-2008	CTL	50	-	2	10	48,7	1,0	1663,4	0,591	0,863	4
11-03-2008	CTL	50	-	2	10	48,7	1,0	1669,6	0,585	0,882	6
13-03-2008	CTL	50	-	2	10	48,7	1,0	1669,9	0,585	0,883	4
01-04-2008	CTL	50	-	2	10	48,7	1,0	1651,7	0,602	0,826	4
02-04-2008	CTL	50	-	2	10	48,7	1,0	1669,6	0,585	0,882	4
09-04-2008	CTL	50	-	2	10	48,7	1,0	1649,9	0,604	0,821	4
22-04-2008	CTL	50	-	2	10	48,7	1,0	1653,4	0,6	0,832	4
23-04-2008	CTL	50	-	2	10	48,7	1,0	1669,6	0,585	0,882	4
28-04-2008	CTL	50	-	2	10	48,7	1,0	1665,7	0,589	0,87	4
29-04-2008	CTL	50	-	2	10	48,7	1,0	1656,1	0,598	0,84	4
04-06-2008	CTL	50	-	2	10	48,7	1,0	1654,6	0,599	0,835	4
12-06-2008	CTL	50	-	2	10	48,7	1,0	1640,2	0,613	0,79	4
12-01-2009	CTL	50	-	2	10	48,7	1,0	1662,3	0,592	0,859	4
15-04-2009	CTL	50	-	2	10	45,5	4,2	1655,4	0,598	0,838	4
16-04-2009	CTL	50	-	2	10	48,7	1,0	1661,1	0,593	0,855	4
20-04-2009	CTL	50	-	2	10	48,7	1,0	1657	0,597	0,843	4
21-04-2009	CTL	50	-	2	10	48,7	1,0	1652,2	0,601	0,828	4
22-04-2009	CTL	50	-	2	10	48,7	1,0	1647,8	0,606	0,814	4
23-04-2009	CTL	50	-	2	10	48,7	1,0	1646,8	0,607	0,811	4
27-04-2009 a)	CTL	50	-	2	10	48,7	1,0	1658,7	0,595	0,848	4
27-04-2009 b)	CTL	50	-	2	10	48,7	1,0	1652,1	0,602	0,828	4
28-04-2009	CTL	50	-	2	10	48,7	1,0	1649,8	0,604	0,82	4
29-04-2009	CTL	50	-	2	10	48,7	1,0	1658,2	0,596	0,847	4
30-04-2009	CTL	50	-	2	10	48,7	1,0	1663,3	0,591	0,862	4

Table 2.3 Notes to preparation of sand samples.

Notes:

*** For intial version of spot pouring hopper**

**** For second version of spot pouring hopper**

1) **Initial version of spot pouring hopper. Halfway through the test problems with static electricity were encountered and a 1 hrs brake was taken to solve the problems with discharging wires.**

   The lever controlling the flow to the hose had a tendency to close (elastic band needed for the closure of the valve), this caused the flow to decrease which would affect the void ratio.

   The ruler used to remove the remaining sand from the container is too thick, needs to be sharp.
2) **Initial version of spot pouring hopper. Base plate installed in container including filter sheet.**
3) **Second version of spot pouring hopper. The preparation took two days (29-10-2007 and 30-10-2009). Problem with dirt in sand which lead to reduced sand flow.**
4) **Second version of spot pouring hopper.**
5) **Second version of spot pouring hopper. The preparation was carried out 19-02-2008.**
6) **Second version of spot pouring hopper. Great care taken to ensure homogenus sample, preventing that the preparation system ran empty due to breaks.**

2.3.5 Perspectives

The existing equipment has been designed with a storage container with a volume of 200 litres, and the used control valve can support tubes with larger diameters. The existing equipment is easily modified with both or either a smaller storage container and different tubes.

A limiting factor in the present setup is the drop height as this is limited by the clearance in the centrifuge building. It is possible increase the drop height by reducing the length of the flexible tube, but it will reduce flexibility during preparation of the sample.

The flow rate controls the density, lower flow giving higher density. Preparation of approximate 180 kg of sample with an orifice plate with a 10 mm hole takes approximate 2 hrs. and gives a relative density of 0.85-0.90. Time taken to prepare sample can be shortened by modification of tube and muzzle – increase diameter of setup with an orifice plate with multiple holes.

2.4 Cone penetration tests

Cone Penetration Testing is possible in the centrifuge at DTU Byg for tests with a circular container. The setup consists of a penetrometer frame and a penetrometer (CPT). Figure 2.10 shows the setup mounted on the centrifuge.

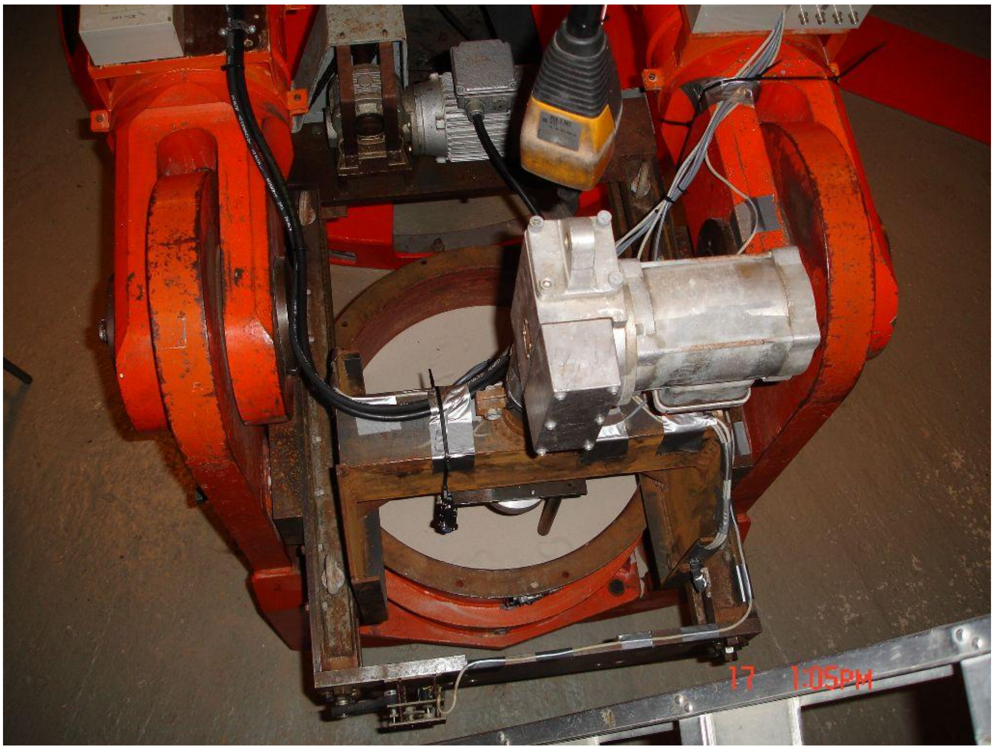


Figure 2.10 CPT setup mounted in centrifuge.

The next sections describe the frame, the penetrometer and the use of the equipment.
Features of the CPT setup:

- The setup is used in combination with a circular container and requires that the container is partly filled with a soil sample - the upper 16 cm of the container must be empty.
- The CPT can measure tip resistance, combined tip and friction (on a part of the cone) resistance and pore pressure. The total driving force is in addition measured.
- The penetrometer frame can move in the horizontal plane along the centre line of the container. It is possible to cover approximate 2/3 of the diameter of the container.

2.4.1 Penetration frame

The penetrometer frame was designed and produced at Danmarks Ingeniørakademi, Bygningsafdelingen (DIAB) and a description is given by Nielsen and Garbarsch (1991). The frame was designed in 1988 by Søren Nielsen and rebuild by Lars Christiansen in 1990, documentation for these is included as a pdf-file on the CD enclosed the present report. The centre of gravity was calculated for the original design and updated in connection with Nielsen and Garbarsch (1991), these calculations are included as a pdf-file on the CD enclosed the present report.
The frame is usable for various penetration / vertical loading tests in the circular container. The general capabilities are:

- Horizontal movement of approximately 21 cm.
- Vertical stroke of approximately 30 cm.
- Maximum push and pull force is approximately 10 kN.
- Penetration velocity is 2.5 mm/sec.

The frame has two 380V motors, one for vertical movement and one for horizontal movement. Standard electrical motors are used, where the direction of the motor rotation is changed by switching two of three phases. The motor for vertical movement has a build-in potentiometer, whereas the horizontal location is monitored by use of an external mounted potentiometer. Both potentiometers are supplied with 5V and give the position as a voltage signal. The position can be calculated in centimetres by:

- Horizontal: ([Voltage signal]-0.38V)×9.17cm/V, zero is 6.6 cm from container wall.
- Vertical: ([Voltage signal]-0.04V)×9.70cm/V, zero is 15 cm from top of container.

The limits of the horizontal movement are defined by 2 micro switches, which prevent out of bound movement and consequential damage to the frame. The upper limit of the vertical movement is likewise fixed by a micro switch, whereas the lower limit is not relevant as the shaft will screw off at a specific lower level.
The penetrometer frame is shown in Figure 2.11.

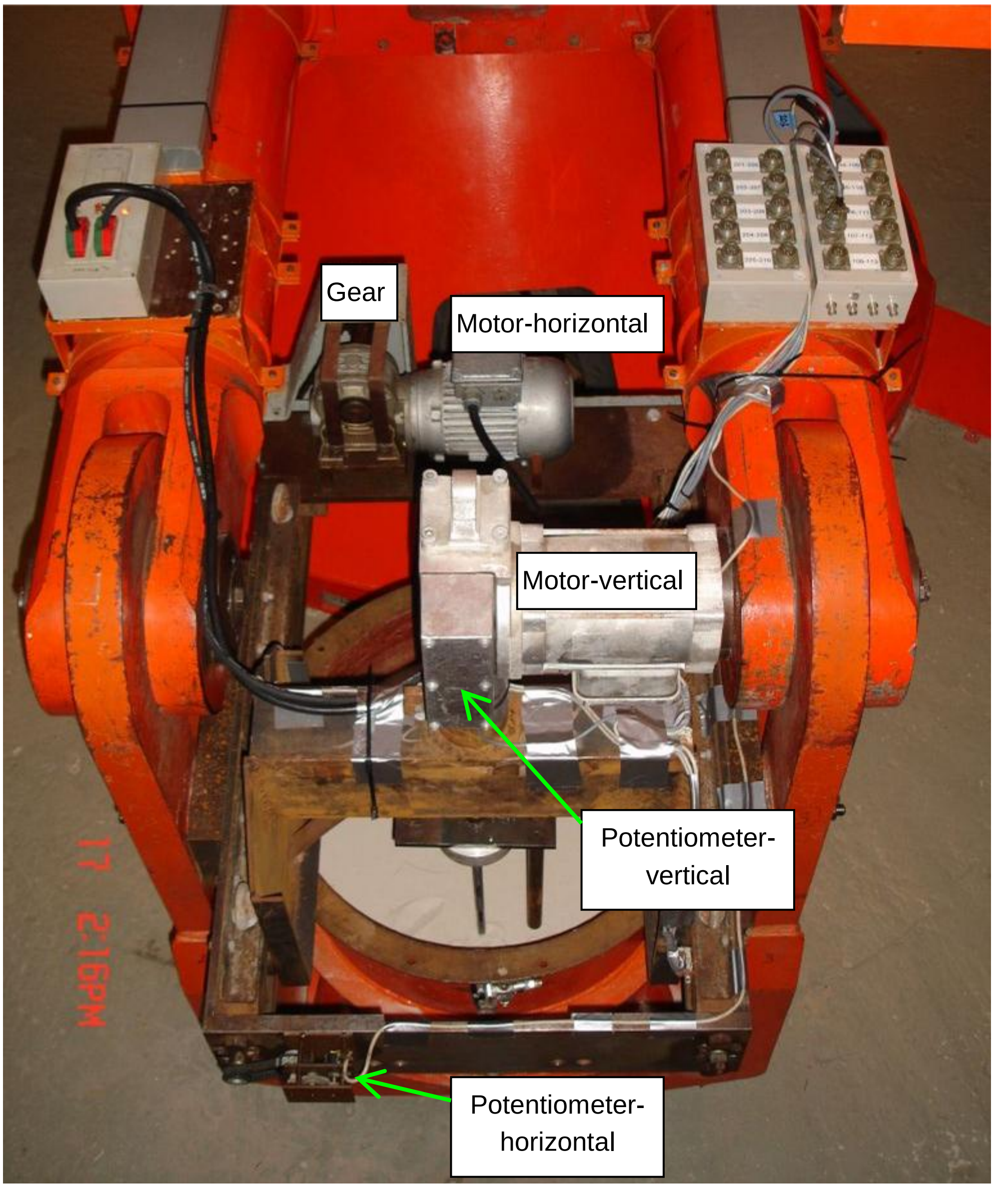
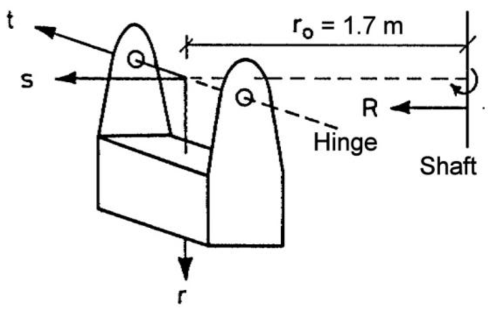


Figure 2.11 Penetrometer frame.

The weight and centre of gravity of the penetrometer frame has been calculated in Nielsen and Garbarsch (1991), and is summarized as:

- Weight: M = 172.7 kg
- Radial direction (from shaft)
  r = 0.176 m.
- Transversal direction, across rotation plane
  s = 0.078 m.
- Transversal direction, in rotation plane
  t = 0.009 m.



2.4.2 Mini-penetrometer (CPT)

A mini-penetrometer (CPT) was purchased by Danmarks Ingeniørakademi, Bygningsafdelingen (DIAB) in 1994 from Istituto Sperimentale Modelli e Strutture, Bergamo Italy (ISMES). The CPT was purchased for the centrifuge setup to verify soil parameters of prepared samples. The cone has been refitted in 2006, where two strain-gauge full-bridges have been replaced.
The CPT was manufactured by ISMES, and the documents submitted with the CPT are included as Appendix A. The length of the cone is 91.3 mm and the diameter is 11.3 mm. The technicians at DIAB supplied the CPT with a rod (approximate length is 280 mm) and a 9 pin serial male plug so the cone fitted the existing penetrometer frame. The CPT is shown in Figure 2.12 and the possible penetration depth is 300 mm. The strain-gauges and wiring were replaced in 2006 by technicians at DTU Byg, Department of Civil Engineering, Technical University of Denmark.

Figure 2.12 Mini penetrometer (CPT).

The CPT is instrumented to measure:

- Tip resistance (TIP), measured behind the tip. Tip area is 1.00 cm^2.
- Tip + Friction resistance (TIP&FRIC), measured on a section directly behind the tip. The friction on the sleeve is for an area of 15.00 cm^2, and it is determined by subtracting the measured tip resistance (TIP).
- Pore pressure (POR), measured behind the tip.

The range of the three measurements is not known, but it is possible to assess reasonable ranges from the original calibration charts supplied by ISMES, cf. Appendix A. Following ranges have been assessed:

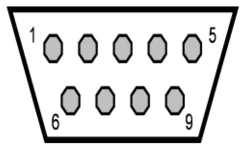
- Tip resistance: ± 10 kN
- Tip + Friction resistance: ± 10 kN
- Pore pressure: 3.5 MPa

The original wiring of the cone is given on page 10 in Appendix A, 4 wires for each measurement - total of 12 wires. The wires for the Tip and the Tip+Friction have been replaced, whereas the wires for the pore pressure transducer have been extended. The new colour codes are given in Table 2.4.
The assembly of the wires in the 9 pin serial male plug (seen to the right in Figure 2.12) is given in Table 2.5.

Table 2.4 New wire colour code.

Signal	**Tip**	**Tip+Friction**	**Pore pressure**
Positive In	Red w. black	Red	Pink (thin)
Negative In	Yellow w. black	Yellow w. grey	Yellow (thin)
Positive Out	Blue w. grey	Blue	Blue (thin)
Negative Out	Green w. grey	Green	Green (thin)

Table 2.5 Wiring of CPT, 9 pin serial plug.

<table>
<tr><th>Pin</th><th>Wires</th><th>Element</th><th>Voltage</th></tr>
<tr><td>1</td><td>Red w. black, Red, Pink (thin)</td><td>Positive In for all 3 measurements.</td><td rowspan="2">5 V</td></tr>
<tr><td>2</td><td>Yellow w. black, Yellow w. grey, Yellow (thin)</td><td>Negative In for all 3 measurements.</td></tr>
<tr><td>3</td><td>Blue w. grey</td><td>Positive Out for Tip resistance.</td><td rowspan="2">Approximate 20 mV at 10 kN</td></tr>
<tr><td>4</td><td>Green w. grey</td><td>Negative Out for Tip resistance.</td></tr>
<tr><td>5</td><td>Blue</td><td>Positive Out for Tip + Friction resistance.</td><td rowspan="2">Approximate 20 mV at 10 kN</td></tr>
<tr><td>6</td><td>Green</td><td>Negative Out for Tip + Friction resistance.</td></tr>
<tr><td>7</td><td>Blue (thin)</td><td>Positive Out for pore pressure.</td><td rowspan="2">Approximate 35 mV at 3.5 MPa</td></tr>
<tr><td>8</td><td>Green (thin)</td><td>Negative Out for pore pressure.</td></tr>
<tr><td>9</td><td></td><td>-</td><td>-</td></tr>
<tr><td colspan="3">The picture to the right shows the location of the pins in the 9 pin serial male plug when seen from the front.</td><td>
</td></tr>
</table>

2.4.3 Calibration of CPT

The cone was calibrated by ISMES in 1994 and the calibration charts from this are included in Appendix A.

Calibration equipment has in 2006 been produced by the technicians at DTU Byg, and the parts for the equipment are shown in Figure 2.13. The calibration setup fits into a range of laboratory load frames and the assembled setup is shown in Figure 2.14.

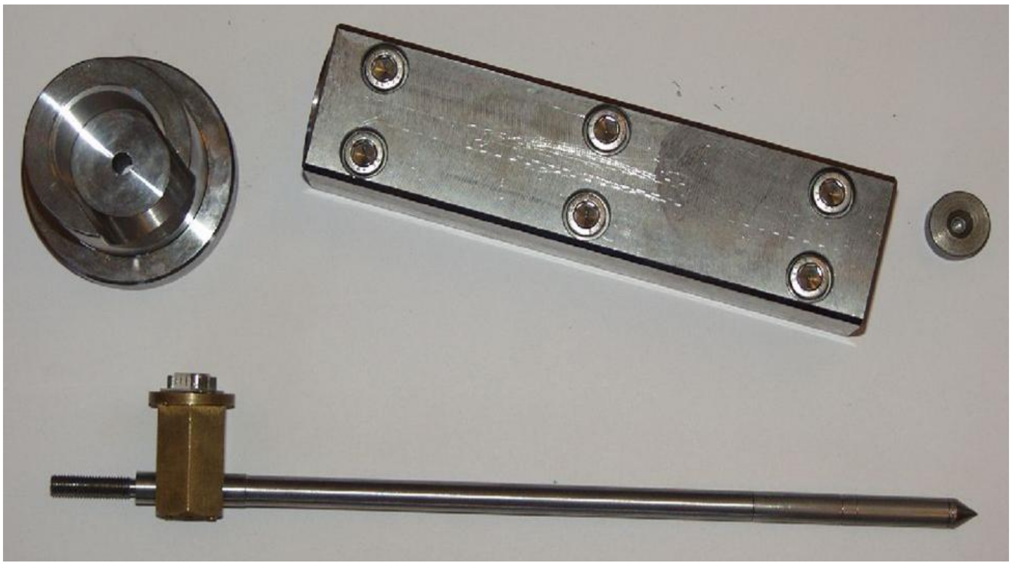


Figure 2.13 Parts for calibration equipment.

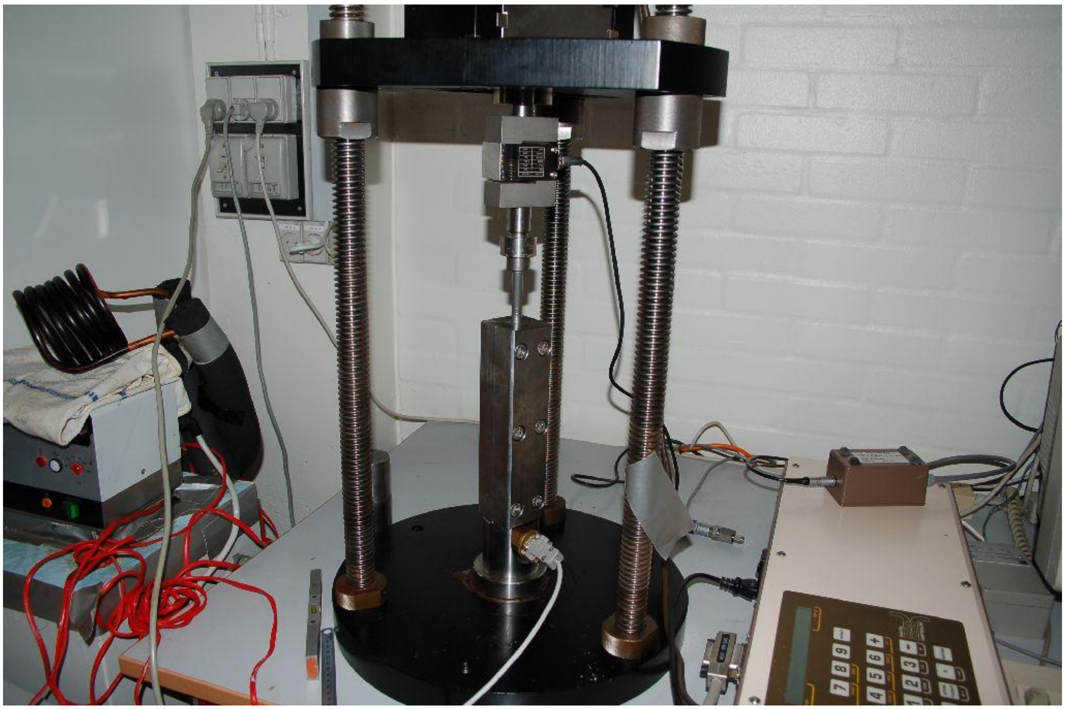


Figure 2.14 Assembled calibration equipment in a CRS loading frame at DTU Byg (CRS: Constant rate of strain).

2.4.4 Setup and controls

Wires

The penetrometer frame is mounted on top of the sample container after the container is placed on the swing cradle. The mini penetrometer and the guide for vertical movement is mounted on the frame after this is placed. A close up of the frame with mini penetrometer and guide is seen in Figure 2.15.

The wiring of the setup includes:

- Two 380V cables for the motors.
- Four 6 pin Amphenol 97 plugs are used to connect the frame and the mini-penetrometer.
  - Plug 104: Total driving force (load cell)
  - Plug 105: Tip resistance (TIP)
  - Plug 106: Tip and friction force (TIP&FRIC)
  - Plug 107: Pore pressure transducer (POR)
- One 20 pin EDAC plug for control electronics and interface with flight computer.

Figure 2.15 Close up of the penetrometer frame with penetrometer and guide.

Controls

A LabVIEW program (Motor.llb and MeasureVI.vi) has been made to carry out the CPT tests in the centrifuge.

The basis of the control system is showed in the diagram in Figure 2.16 and the control components are shown in Figure 2.17.

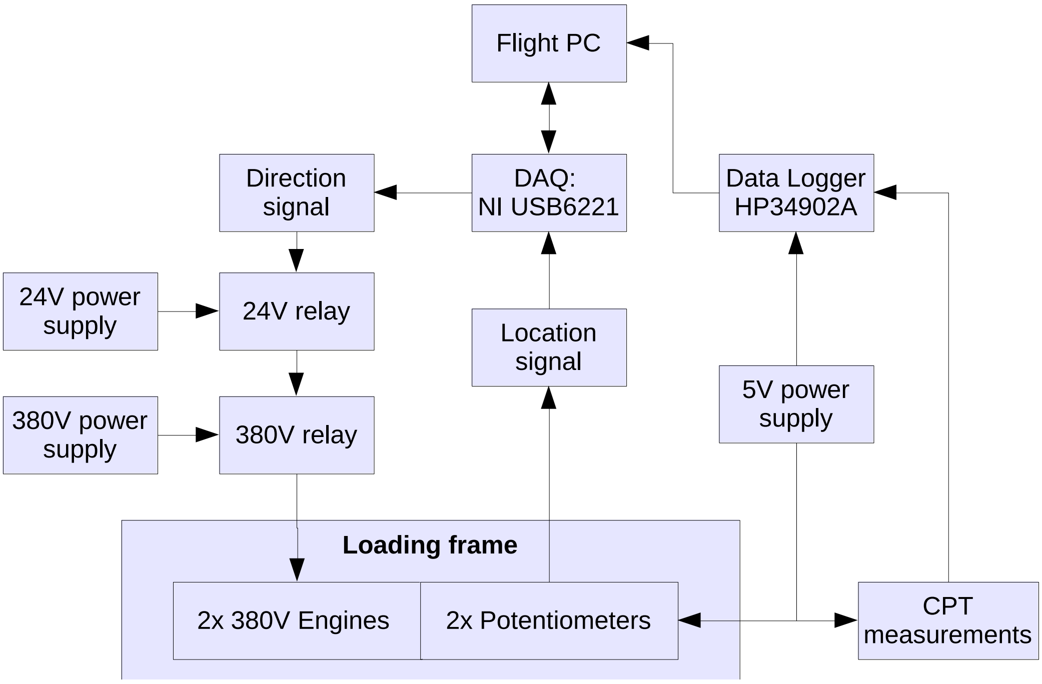


Figure 2.16 Control diagram for CPT setup.

Figure 2.17 Control components for CPT setup.

2.4.5 CPT in prepared samples

The preparation of sand samples are tested by use of cone penetration tests (CPT) and the results from three CPTs are presented in Figure 2.18 - Figure 2.20, while Klinkvort & Hansen (2007) include results from fourteen CPTs.

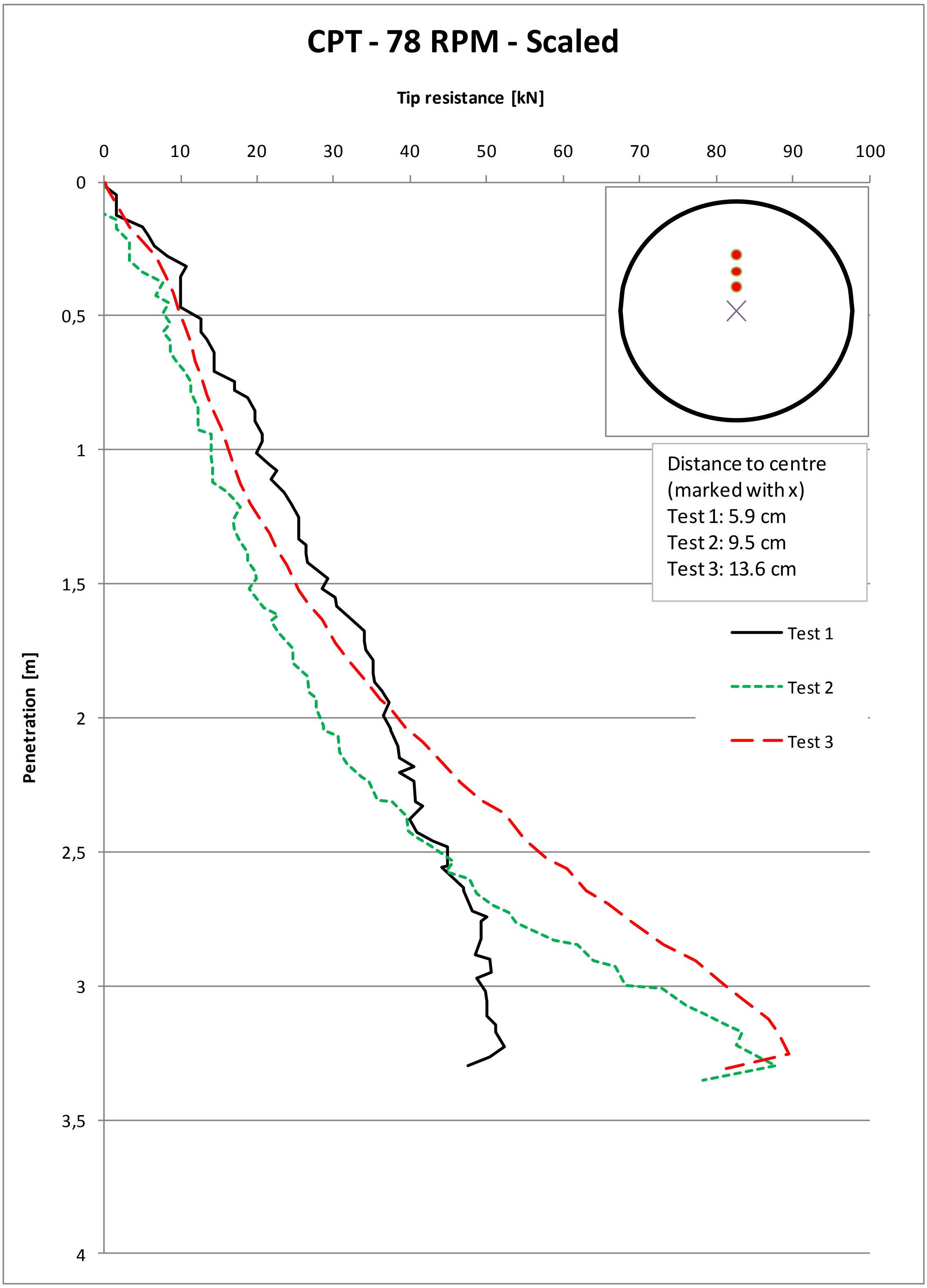


Figure 2.18 CPT Series 1 carried out September the 7th 2006.

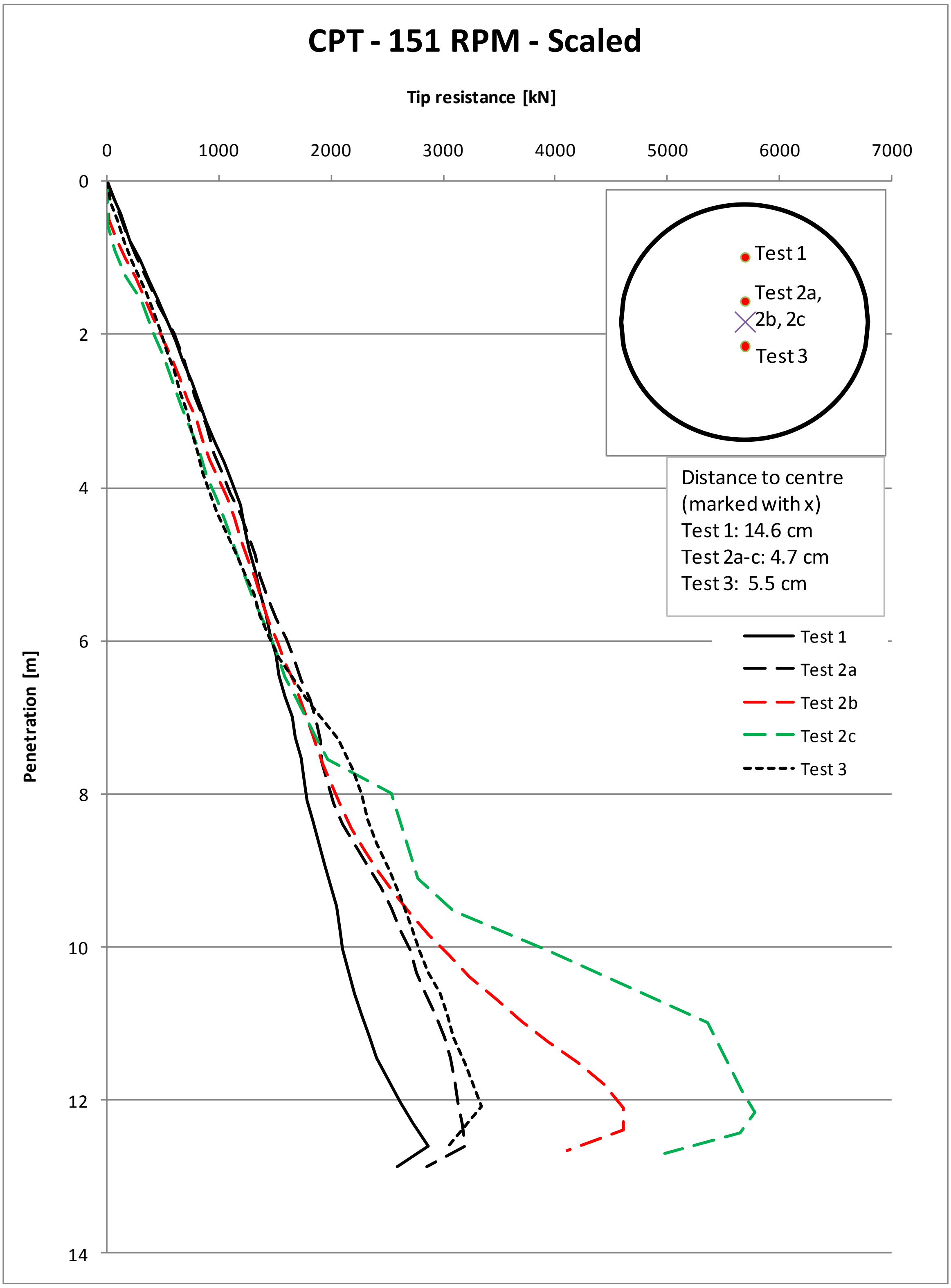


Figure 2.19 **CPT Series 2 carried out November the 6th 2007.**

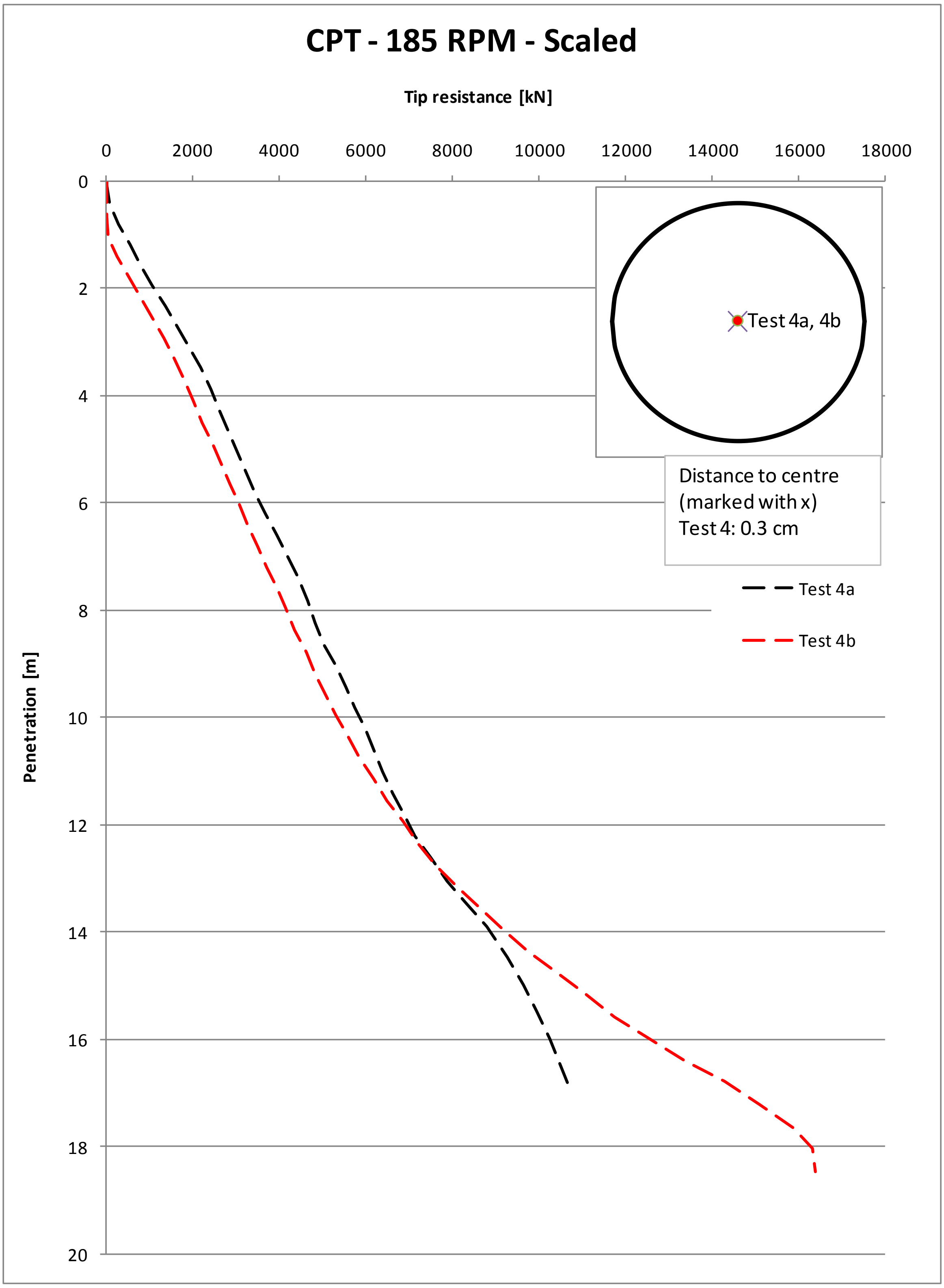


Figure 2.20 CPT Series 3 carried out November the 6th 2007.

2.5 Consolidation tests

The applied sand sample is consolidated during centrifuge testing, primary during start up, and this consolidation process is investigated by consolidation tests.
The setup for the consolidation tests is shown in Figure 2.21 and consists of two Linear Variable Differential Transformers (LVDTs) mounted on a steel beam. A thin Plexiglass plate is the interface between the LVDTs and the sand.

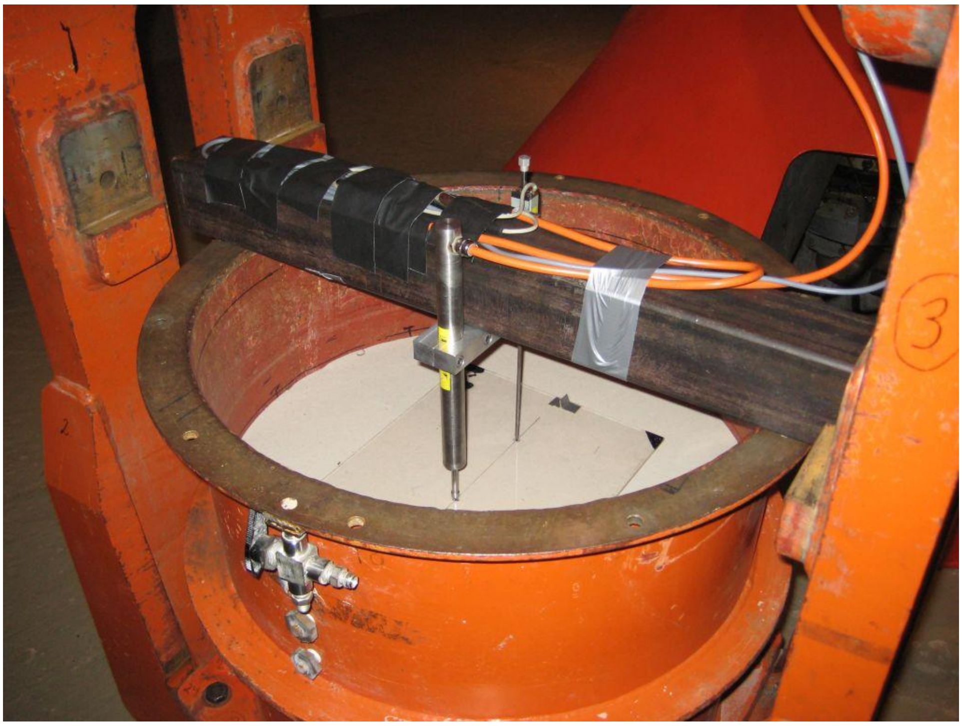


Figure 2.21 Setup for consolidation test.

Four consolidation tests have been carried out; results from three are show in Figure 2.22 - Figure 2.24, while one is included in Klinkvort & Hansen (2007).

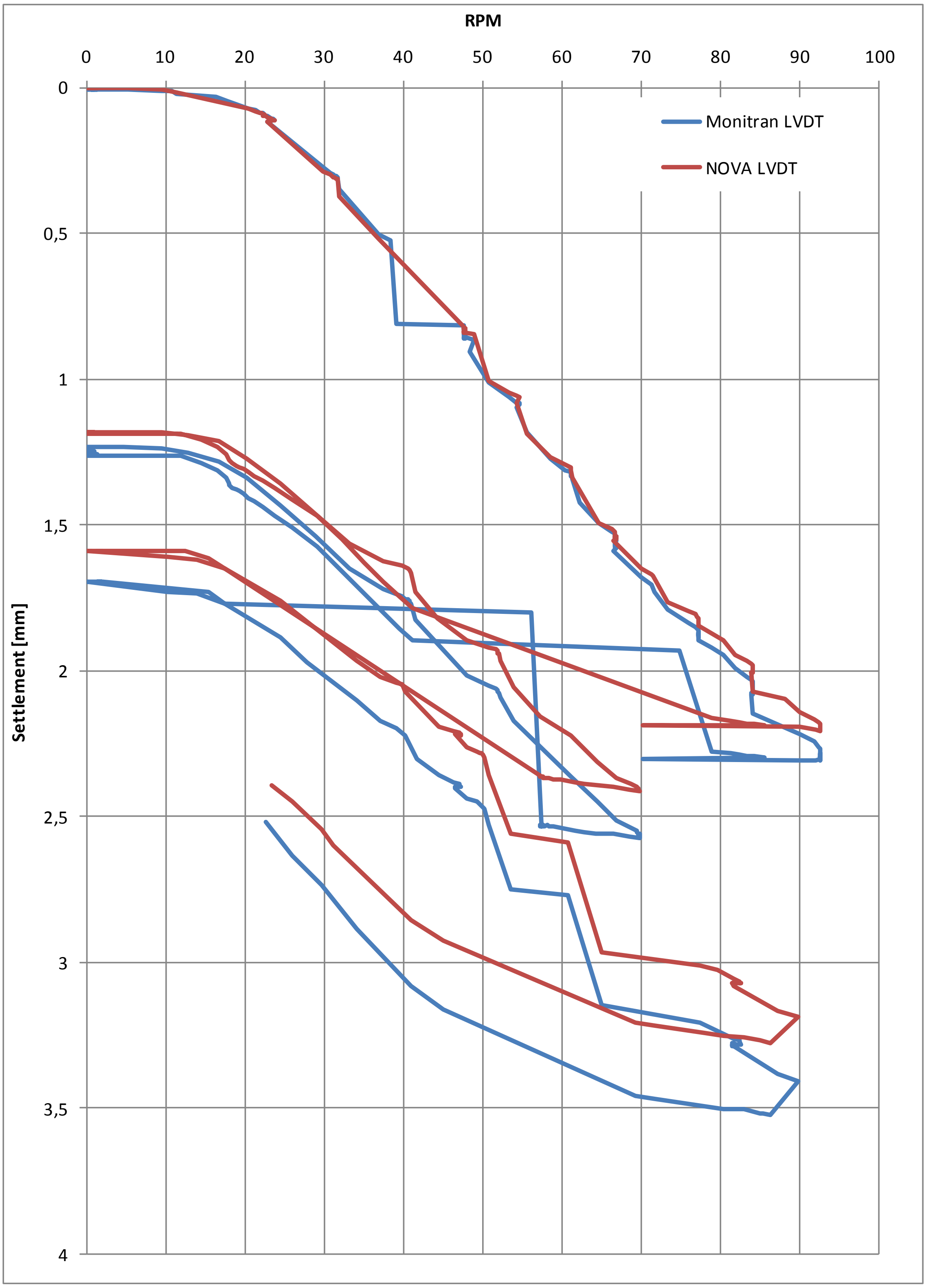


Figure 2.22 Consolidation test carried out January the 15th 2007.

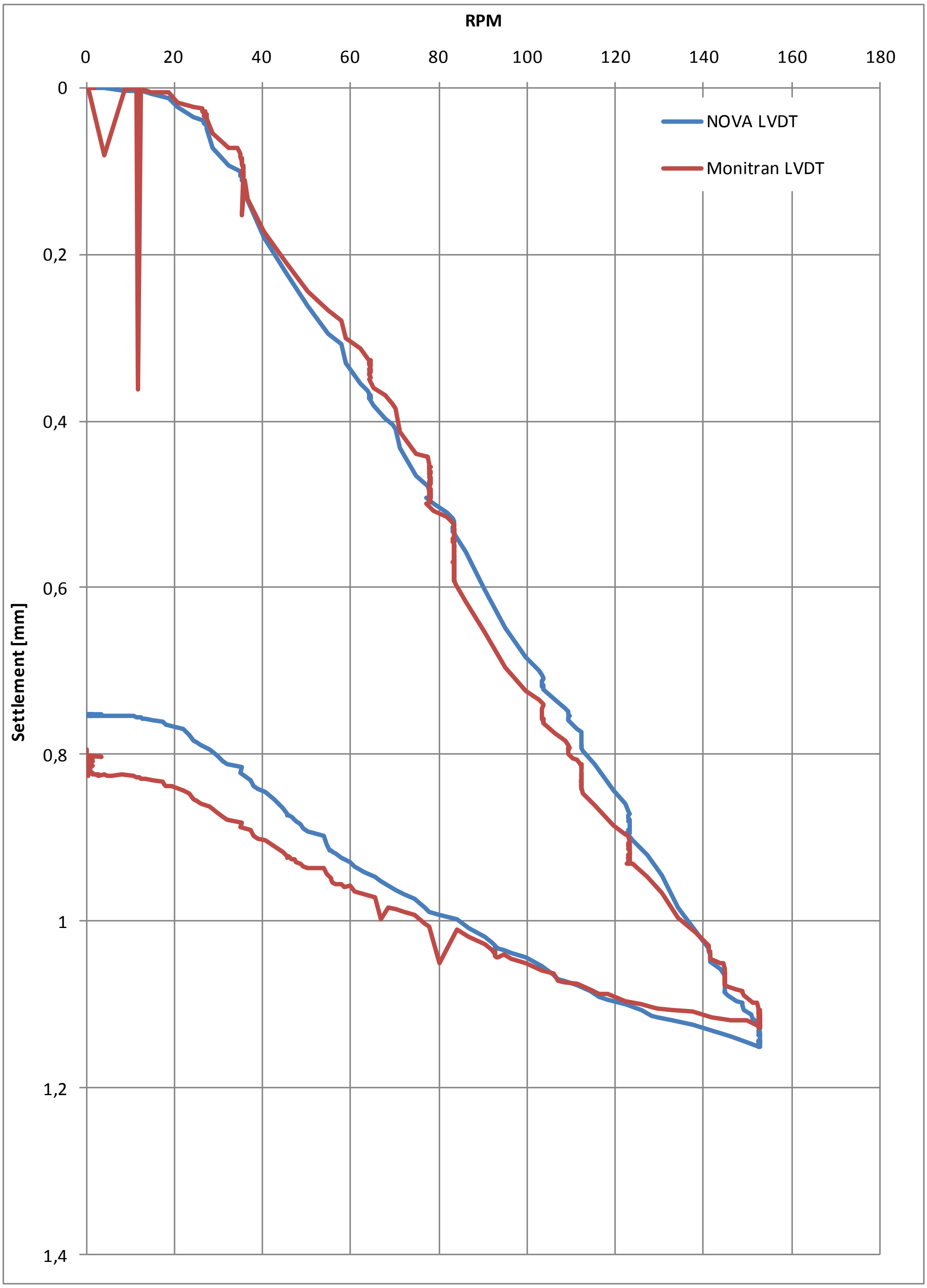


Figure 2.23 **Consolidation test carried out October the 31th 2007.**

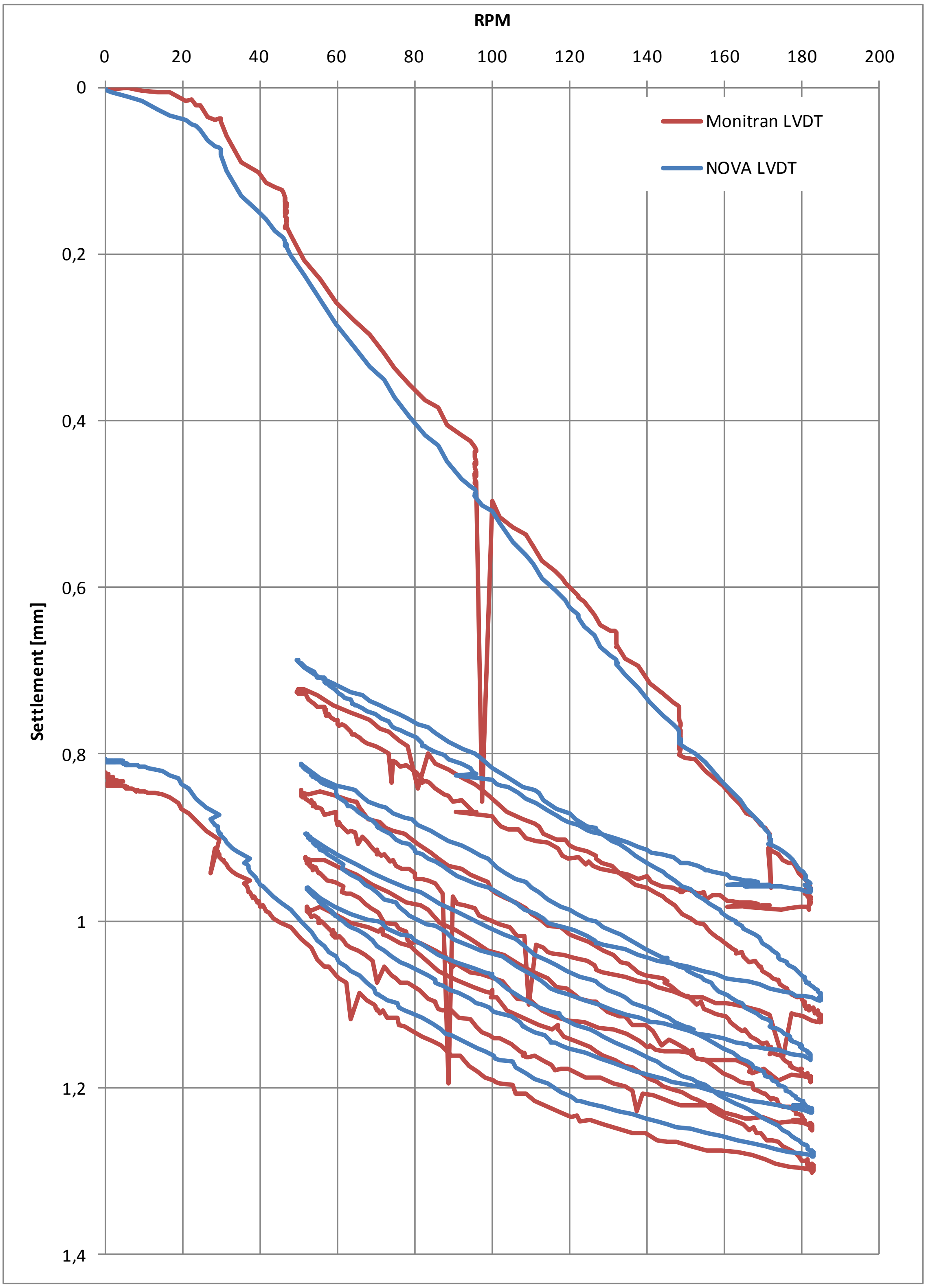


Figure 2.24 Consolidation test carried out February the 21th 2007.

2.6 Lateral loading system

A loading frame for tests on laterally loaded piles was constructed by Peder N. Knudsen (Knudsen, 1982), and was used in the Ph.D. study by Frands Haahr (Haahr 1989). A description of the use of the setup along with the controls of that time is given in Haahr (1989). Figure 2.25 shows the setup mounted in the centrifuge.

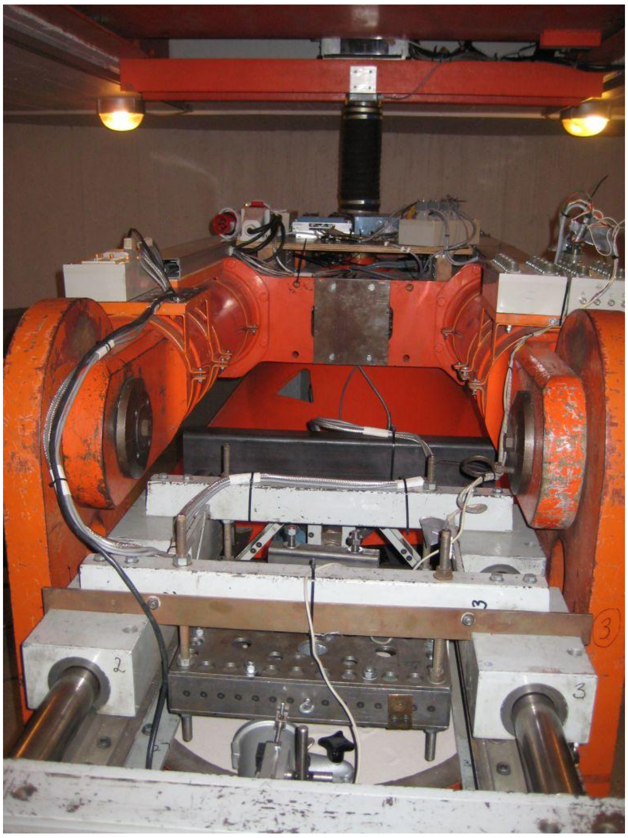


Figure 2.25 Loading frame mounted in centrifuge.

The next chapters describe the frame, the controls and the use of the equipment.
The usability of the lateral loading frame is:

- Lateral loading of a mono pile or a pile group with either fixed pile head or free pile head. The piles are fixed in axial direction and one way lateral load can be applied.
- Pile model diameter is maximum 40 mm for testing mono piles and 28 mm for tests with pile groups.
- The updated control system is based on a LabVIEW interface and both static and cyclic tests can be carried out.

2.6.1 Loading frame

The lateral loading frame is based on an outer frame supporting the engine and the loading platform. The loading platform is mounted on at set of radial linear bushings and works as a pile cap for the pile(s) tested. The loading frame is shown in Figure 2.26.
Each pile is mounted in the loading platform by use of a connection piece consisting of a hinge and a load cell, see Figure 2.27 for assembled pile, load cell and hinge. The load cell is mounted in the loading platform and fixed by an expansion bolt.

The mounted loading frame on the container is sketched in Figure 2.28, where the main definitions and dimensions are given.
Lateral displacement is measured by use of a LVDT mounted on the outer frame and attached to the loading platform, see Figure 2.29

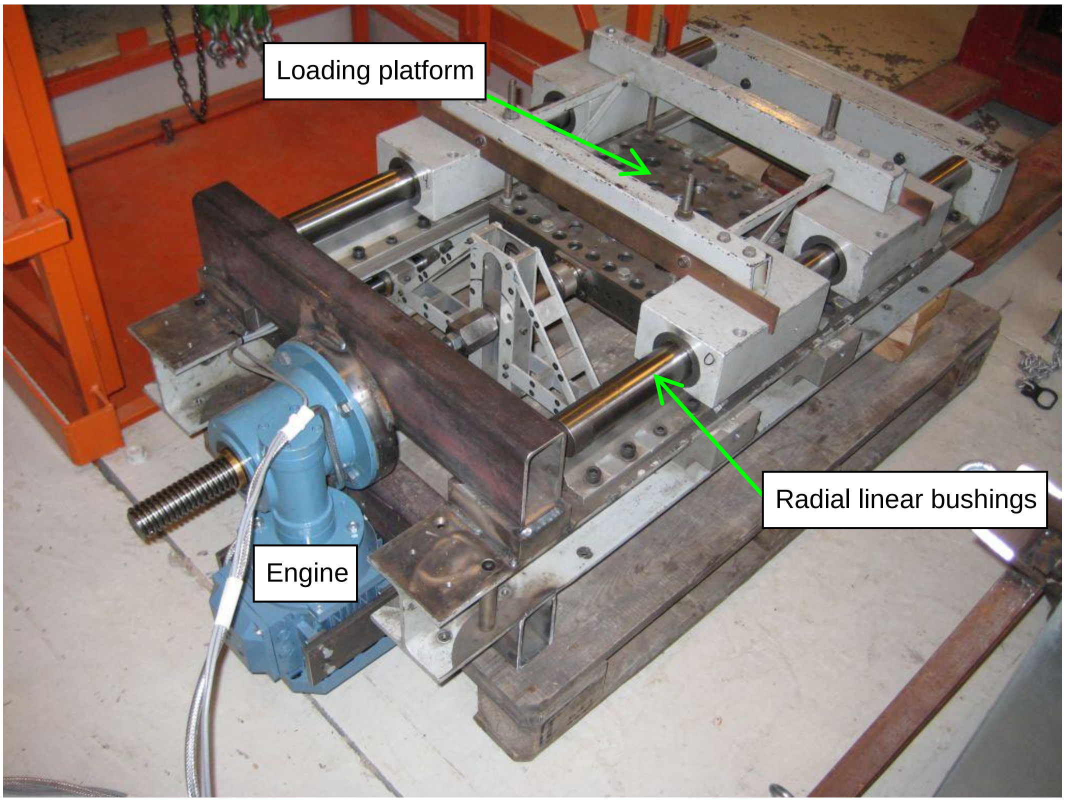


Figure 2.26 Loading frame.

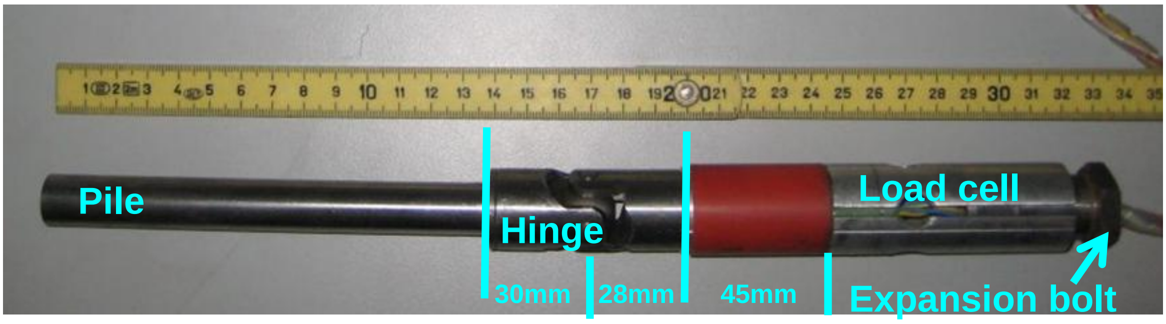


Figure 2.27 ø16mm pile with hinge and load cell, Haahr (1989).

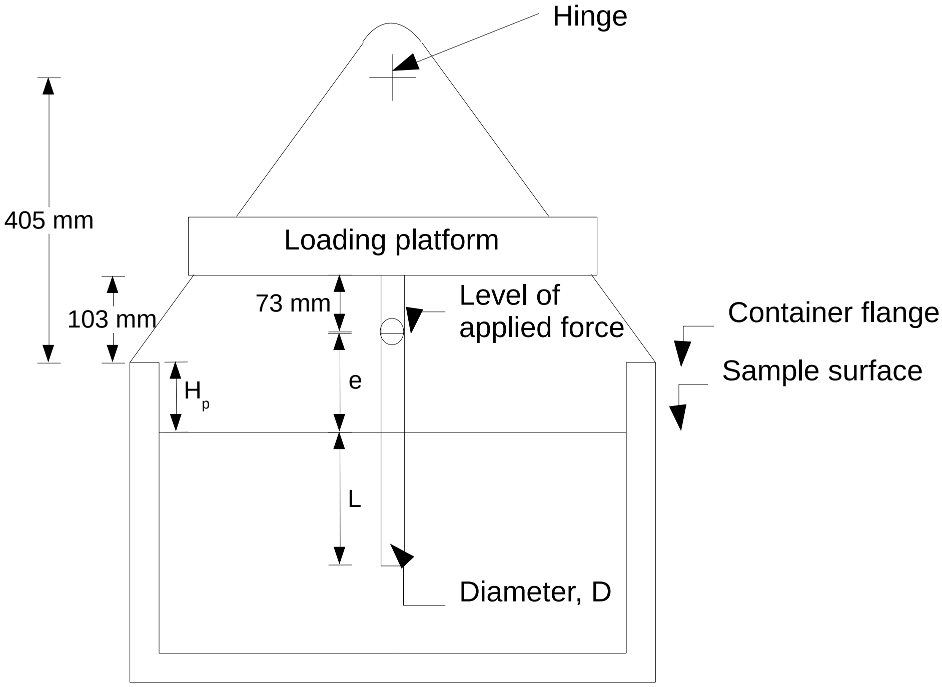


Figure 2.28 Sketch of mounted loading frame.

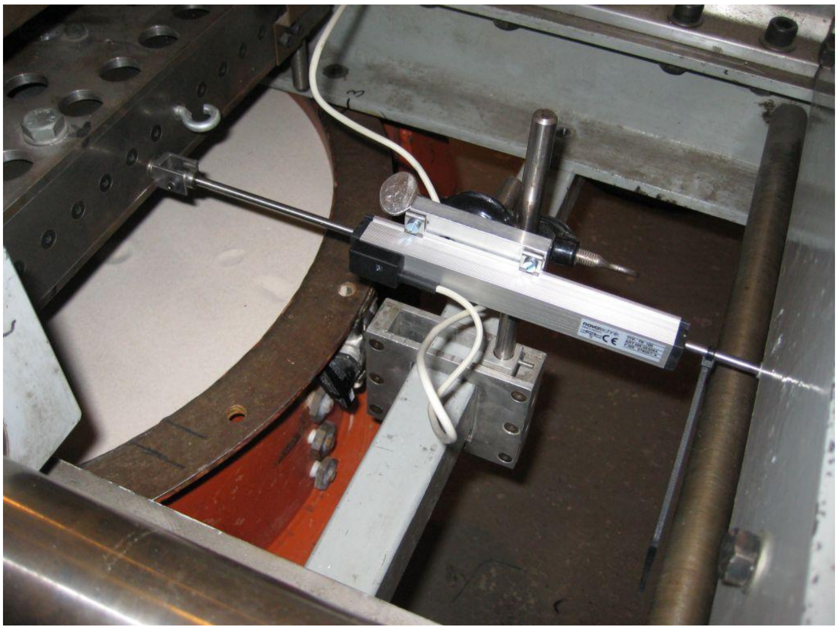


Figure 2.29 LVDT mounted on the loading frame.

The lateral loading frame has been renovated / upgraded in 2006-2007 with:

- New 380V ABB AC motor 1.1 kW and Danfoss VLT2800 frequency converter.
- Application of two micro switches to prevent out of bound movement and consequential damage to the setup. The loading platform has a horizontal displacement range of 15.4 cm.
- New NOVO TR100 LVDT.

- New load cell produced at DTU, Department of civil engineering (DTU Byg) and Department of mechanical engineering (DTU Mek). The new load cell is made of high strength steel (CrNI) and has a range of ±18 kN.
- Application of strain gauge amplifier for the load cell directly at the loading platform, see Figure 2.30. (from RS Components: amplifier RS 846-171 and circuit RS 435-692).
- Adjustment of loading platform to allow installation of ø40 mm model pile.
- Mounting on loading platform to fix piles in axial direction. This was included when it was observed that the pile had an upward movement during cyclic lateral loading. The mounting is shown to the right in Figure 2.30. The thread bars can be extended and the beam applied to install the pile by continuous screwing the nuts.

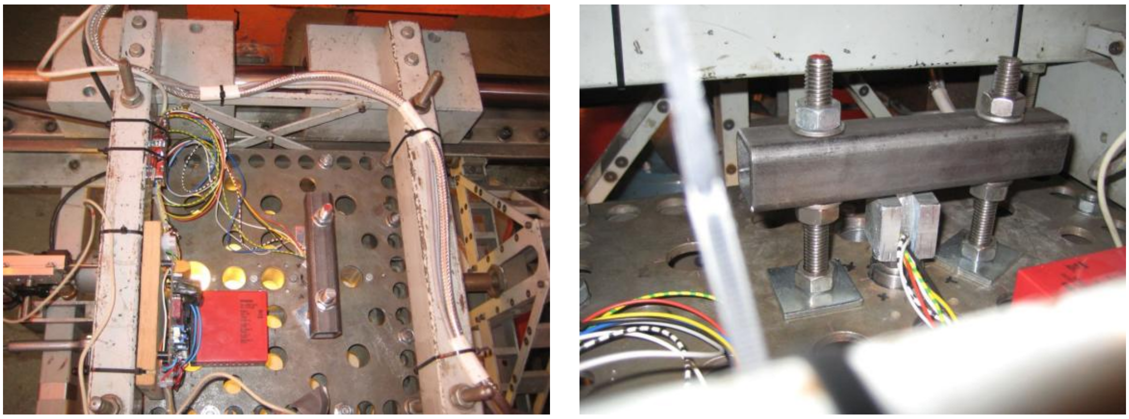
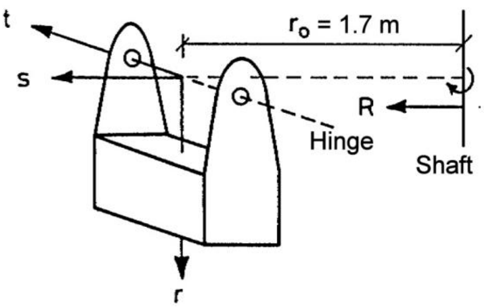


Figure 2.30 Mounting for axial fixity of piles and strain gauge amplifier.

The modifications listed above have included some structural changes to the original loading frame, and determination of the centre of gravity was carried out, documentation is included as a pdf-file on the CD enclosed the present report. The modified setup is divided into three parts; loading frame, frequency converter and beam supporting the LVDT.
The mass and centre of gravity of the setup is summarized as:

Loading frame
- Weight: M = 273.6 kg
- Radial direction (from shaft)
  r = 0.293 m.
- Transversal direction, across rotation plane
  s = -0.020 m.
- Transversal direction, in rotation plane
  t = 0.015 m.



LVDT beam for loading frame
- Weight: M = 4.7 kg
- Radial direction (from shaft)
  r = 0.424 m.
- Transversal direction, across rotation plane
  s = 0.371 m.
- Transversal direction, in rotation plane
  t = 0.000 m.

Frequency converter
- Weight: M = 4.1 kg
- Radial direction (from shaft)
  r = -1.080 m.
- Transversal direction, across rotation plane
  s = 0.000 m.
- Transversal direction, in rotation plane
  t = 0.000 m.

2.6.2 Preparation and controls

Preparation of pile test

Following procedure is applied to prepare a lateral pile load test:

- Preparation of soil sample, see section 2.3.
- Mounting of lateral loading frame on top of the sample container, and placement of the two on the swing cradle.
- Mounting of frequency converter and wires for the engine.
- Installation of pile and load cell along with assembly of data acquisition and control system.

The setup can either be controlled manually directly from the centrifuge control room or by use of a LabVIEW program on the flight computer. The two different control setups are described in the next sections.

Manual control

A simple control box as been made to adjust the loading platform on the loading frame during installation and to perform simple lateral load tests. The control box has one switch for choice of direction and a potentiometer for velocity.

The basis of the control system for manual control is showed in Figure 2.31.

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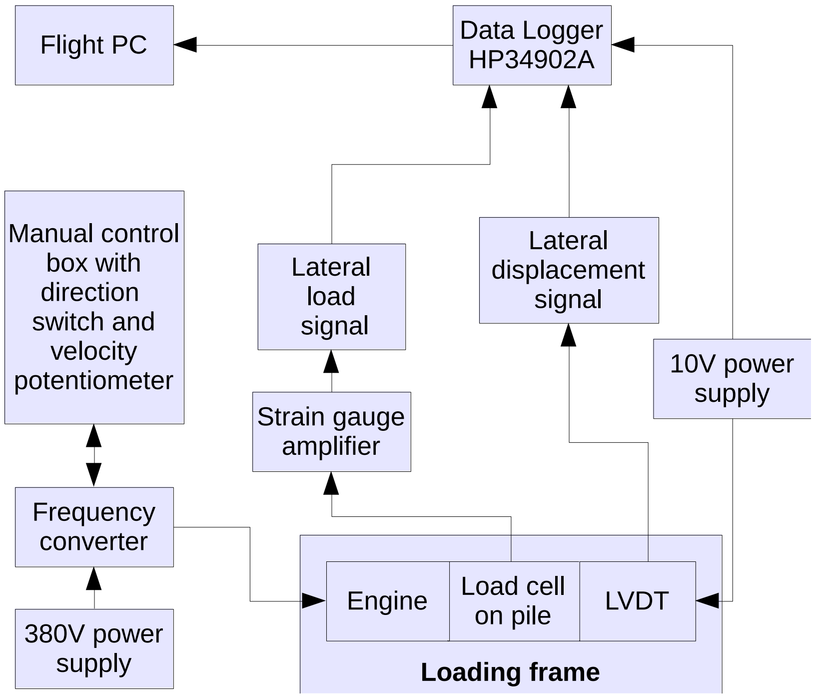


Figure 2.31 Diagram for manual control of loading frame.

The wiring of the setup is:

- 380V power supply to the frequency converter
- 380V cable connecting the frequency converter and engine
- 9 pin serial plug to connect the manual control box to the frequency converter
- 9 pin serial plug to connect the strain gauge amplifier to the load cell

- Three 6 pin Amphenol 97 plugs to connect the load cell on the pile and the LVTD to the datalogger.
  - Plug 104: LVDT and 10V power supply
  - Plug 105: Load cell in primary direction (displacement direction)
  - Plug 106: Load cell in secondary direction (transversal direction)

LabVIEW control

A LabVIEW program (LoadMeasurement) has been programmed by Eric Jensen to carry out cyclic lateral load tests with feedback control.
The basis of the control system is showed in Figure 2.32.

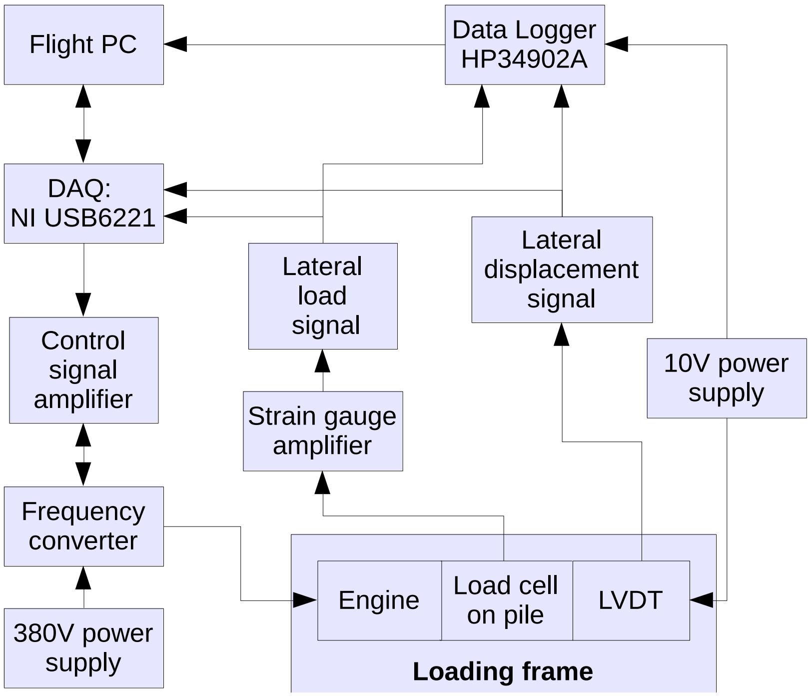


Figure 2.32 **Diagram for LabVIEW control of loading frame.**

The wiring of the setup is:

- 380V power supply to the frequency converter
- 380V cable connecting the frequency converter and engine
- 9 pin serial plug to connect the data acquisition device (DAQ) to the frequency converter
- Two 9 pin serial plugs connects the strain gauge amplifier to the load cell and the DAQ.
- 4 pin DIN plug to connect the LVDT to the DAQ.
- Three 6 pin Amphenol 97 plugs to connect the load cell on the pile and the LVTD to the datalogger.
  - Plug 104: LVDT and 10V power supply
  - Plug 105: Load cell in primary direction (displacement direction)
  - Plug 106: Load cell in secondary direction (transversal direction)

2.7 Calibration of equipment

The measuring equipment listed below have been used in the physical tests. The prepared calibration sheets are included as pdf-files on the CD enclosed the present report. A summary of the calibration sheet is given in Table 2.6 and Table 2.7.

- 5000 N load cell from Burster, type 8521 with serial number 47479.
- Mini-penetrometer (CPT) from Istituto Sperimentale Modelli e Strutture, Bergamo Italy (ISMES).
- 40 mm LVDT from Monitran, type MTN/IEISW20 with serial number 77035.
- 40 mm LVDT from NOVO, type TR40.
- 100 mm LVDT from NOVO, type TR100.
- Two 2 kN load cells constructed at Soil Mechanics Laboratory Technical University of Denmark (DTU) and described in Haahr (1989).
- One new 18 kN load cell constructed at Department of civil engineering (DTU Byg) and Department of mechanical engineering (DTU Mek) at Technical University of Denmark (DTU). The load cell has the same dimensions as the original load cells described in Haahr (1989), but is made of high strength steel (NiCr).

Table 2.6 Calibration of measuring equipment part 1/2.

Equipment	Burster 5000 N, Kraftaufnehmer Typ 8521, SN 47479					
		Reference	Unit = a * Voltage + b		Test range	
Date	User	supply	a	b	Minimum	Maximum
25-01-2006	CTL	10 V	29,7624 kg/mV	1,6609 kg	0 kg	272 kg
17-03-2006	CTL	10 V	29,8068 kg/mV	1,8147 kg	0 kg	272 kg
05-09-2006	CTL	10 V	29,8498 kg/mV	1,2436 kg	0 kg	270 kg
27-02-2007	CTL	10 V	29,6594 kg/mV	1,7141 kg	0 kg	270 kg
Equipment	Mini Cone Penetrometer (CPT) - Tip resistance					
		Reference	Unit = a * Voltage + b		Test range	
Date	User	supply	a	b	Minimum	Maximum
16-01-2007	CTL	5 V	-645,65 N/mV	-3375,83 N	0 N	10032 N
Equipment	Mini Cone Penetrometer (CPT) - Tip & Friction resistance					
		Reference	Unit = a * Voltage + b		Test range	
Date	User	supply	a	b	Minimum	Maximum
16-01-2007	CTL	5 V	-639,74 N/mV	-2370,29 N	0 N	10032 N
Equipment	Monitran, MTN/IEISW20 LVDT					
		Reference	Unit = a * Voltage + b		Test range	
Date	User	supply	a	b	Minimum	Maximum
11-01-2007	CTL	10 V	-27,7434 mm/V	1,0223 mm	0 mm	40 mm
16-03-2007	CTL	10 V	27,0945 mm/V	-5,4895 mm	0 mm	40 mm
21-02-2008	CTL	10 V	-26,9137 mm/V	56,032 mm	0 mm	40 mm
25-02-2008	CTL	10 V	-26,8474 mm/V	50,8536 mm	0 mm	40 mm
Equipment	NOVO TR40 LVDT					
		Reference	Unit = a * Voltage + b		Test range	
Date	User	supply	a	b	Minimum	Maximum
11-01-2007	CTL	5 V	10,5022 mm/V	-52,652 mm	0 mm	40 mm
17-03-2007	CTL	5 V	-10,4415 mm/V	48,2555 mm	0 mm	40 mm
21-02-2008	CTL	5 V	10,5063 mm/V	-1,8069 mm	0 mm	40 mm
Equipment	NOVO 100mm LVDT					
		Reference	Unit = a * Voltage + b		Test range	
Date	User	supply	a	b	Minimum	Maximum
28-02-2008	CTL	10 V	-10,2279 mm/V	102,7562 mm	0 mm	100 mm

Table 2.7 Calibration of measuring equipment part 2/2.

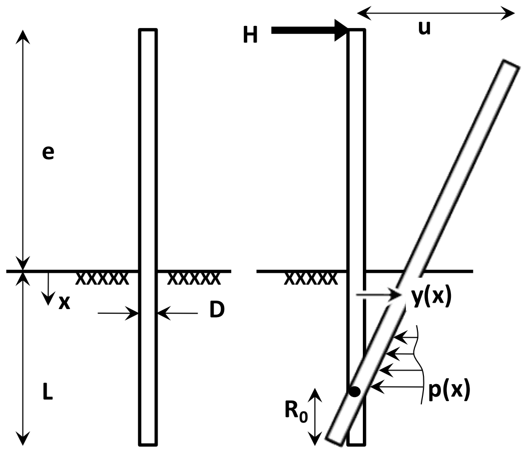
Equipment	LC 7, FRH Load cell, "Blue-yellow direction"						
Date	User	Reference	Unit = a * Voltage + b		Test range		
			a	b	Minimum	Maximum	Note
04-03-2008	CTL	5 V	127,354 N/mV	32,238 N	0 N	1840 N	1
17-06-2008	CTL	5 V	-125,741 N/mV	-49,844 N	0 N	1980 N	2
30-04-2009	CTL	Amplifier	-1377,36 N/V	-314,05 N	0 N	1960 N	3
Note 1	*Calibrated at centrifuge with electronics at the beam*						
Note 2	*Calibrated at standard measuring table at BYG.DTU*						
Note 3	*Calibrated at standard measuring table at BYG.DTU with strain gauge amplifier*						
Equipment	LC 7, FRH Load cell, "Black-red direction"						
		Reference	Unit = a * Voltage + b		Test range		
Date	User	supply	a	b	Minimum	Maximum	Note
17-06-2008	CTL	5 V	-124,2 N/mV	-128,467 N	0 N	1980 N	1
Note 1	*Calibrated at standard measuring table at BYG.DTU*						
Equipment	LC 6, FRH Load cell, "Blue-yellow direction"						
		Reference	Unit = a * Voltage + b		Test range		
Date	User	supply	a	b	Minimum	Maximum	Note
17-06-2008	CTL	5 V	-125,647 N/mV	-103,777 N	0 N	1980 N	1
Note 1	*Calibrated at standard measuring table at BYG.DTU*						
Equipment	LC 6, FRH Load cell, "Black-red direction"						
		Reference	Unit = a * Voltage + b		Test range		
Date	User	supply	a	b	Minimum	Maximum	Note
17-06-2008	CTL	5 V	-122,493 N/mV	-89,396 N	0 N	1980 N	1
Note 1	*Calibrated at standard measuring table at BYG.DTU*						
Equipment	New LC (Load cell), "Blue-yellow direction"						
		Reference	Unit = a * Voltage + b		Test range		
Date	User	supply	a	b	Minimum	Maximum	Note
18-06-2008	CTL	5 V	0,4541 kN/mV	-0,7246 kN	0 kN	17,3 kN	1
30-04-2009	CTL	Amplifier	-2,3486 kN/V	0,0514 kN	0 kN	15,3 kN	2
Note 1	*Calibrated at standard measuring table at BYG.DTU*						
Note 2	*Calibrated at standard measuring table at BYG.DTU with strain gauge amplifier*						
Equipment	New LC (Load cell), "Black-red direction"						
		Reference	Unit = a * Voltage + b		Test range		
Date	User	supply	a	b	Minimum	Maximum	Note
18-06-2008	CTL	5 V	0,458 kN/mV	-0,3435 kN	0 kN	17,3 kN	1
Note 1	*Calibrated at standard measuring table at BYG.DTU*						

3. Lateral load tests

The static and cyclic behaviour of laterally loaded large diameter rigid piles in dry sand are investigated by use of physical modelling in a geotechnical centrifuge. The aim is to investigate:

- Initial stiffness of the piles
- Static behaviour and ultimate bearing capacity
- Stiffness degradation due to cyclic loading
- Influence on ultimate bearing capacity from cyclic loading.

The physical models represent prototype pile with a diameter (D) of 1 to 3 m, an embedment length (L) of 6 to 10 D and a load eccentricity (e) of 2.5 to 6.5 m above sand surface.



e:	Load eccentricity
L:	Embedment length
D:	Diameter
H:	Load on pile top
u:	Deflection at pile top
R_0:	Distance from pile tip to rotation centre.
x:	Depth below sand surface
p(x):	Soil resistance at depth x
y(x):	Pile deflection at depth x.

Figure 3.1 Basic pile definitions.

The static and cyclic behaviour is investigated by a series of tests. The force at pile top is in the static tests increased slowly until maximum pile capacity is reached.

In the cyclic tests the pile is subject to a series of force controlled load cycles followed by a static test. The force controlled load cycles consist of three phases: 1) a phase with large cycles, 2) a phase with smaller cycles and 3) a phase with large cycles. The cycles in phase 1) and 3) are equal.

The test program for investigating the behaviour of lateral loaded large diameter rigid piles is given in Table 3.1.

Table 3.1 Lateral load tests

	D = 1 m	D = 2 m	D = 3 m
L = 6D	s , c	s , c	s , c
L = 8D	s , c	s , c	s , c
L = 10D	s , c	s , c	NA

L = embedment length, D = pile diameter, s = static test, c = cyclic test
Diameter is prototype dimension.

Results from the tests on piles with a prototype diameter (D) of 1 m and 2 m are presented in Appendix B, some of the tests have been carried out multiple times due to either mishaps or to check reproducibility.
The four tests (two static and two cyclic) on piles with a diameter of 3 m were carried out by laboratory assistant Rasmus Klinkvort and the results are presented in a Danish data report (Klinkvort 2009b)) included as Appendix C. The calibration factors for the load cell and LVDT given in the data report is correct but an error occurred when the results were plotted and thus are figures 1 to 4 in the data report erroneous. Updated figures are given in Appendix B.
The tests listed in Table 3.1 have been supplemented by tests carried out on piles with a prototype diameter of 1 m in connection with a master thesis (Klinkvort 2009a), and an article (Klinkvort et al. 2010). The supplementary test program is given in Table 3.2, and the results are reprinted in Appendix B.

Table 3.2 Supplementary lateral load tests. Prototype diameter is 1 m.

	L = 6D	L = 8D	L = 10D
H = 2.5D	S , c	S , c	S , c
H = 4.5D	s , c	s# , c	s s*
H = 6.5D	s , c	s s*	s*

Capital letters are tests carried out by the author of the present laboratory report.
*Tests marked with * are from Klinkvort et al. (2010).*
The test with # is doubled by the author.
L = embedment length, D = pile diameter, s/S = static test, c = cyclic test, H = load height above sand surface.

Three additional lateral load tests have been carried out in the present study: Two static tests on a pile with a diameter and a length of 1 m and 11.9 D, respectively, and a single static test on an aluminium pile with a diameter and a length of 1 m and L = 24.9 D, respectively. Results are presented in Appendix B.
The scaling factor, N, for each lateral load test is determined for an effective level (effective centrifuge radius) that ensures a minimum of error between the stress field of the model and the corresponding prototype. The effective level is equal to one-third of the embedded pile length (Taylor, 1995), and the scaling factor is given along with the test results in Appendix B.
Initial analysis of the obtained data from the cyclic tests showed significant noise. A filter (a MatLab programme) was based on a method described in Hansen (2008) created by Klinkvort (2009a). This filter has been applied to all the cyclic test results presented in the present laboratory report. The effect of the filter applied is shown in Figure 3.2.

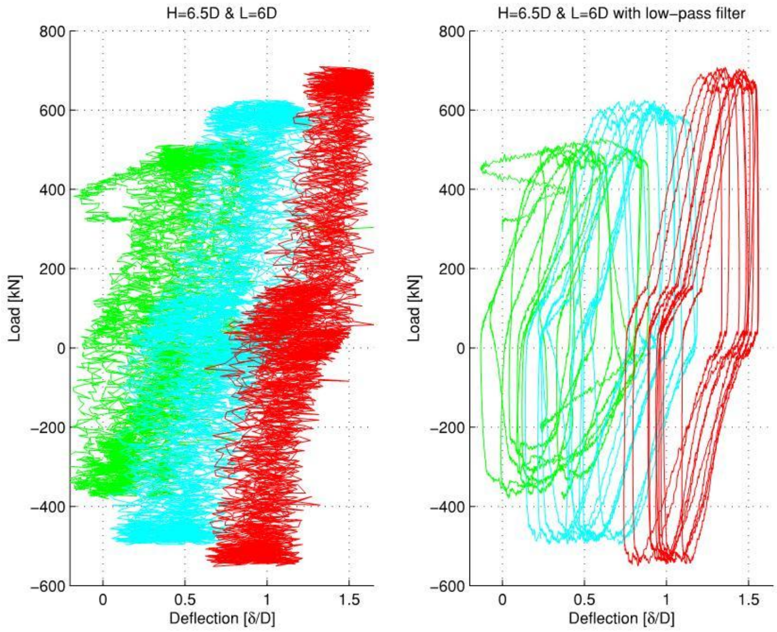


Figure 3.2 Plot of raw and filtered data, Figure 6.16 from Klinkvort (2009a).

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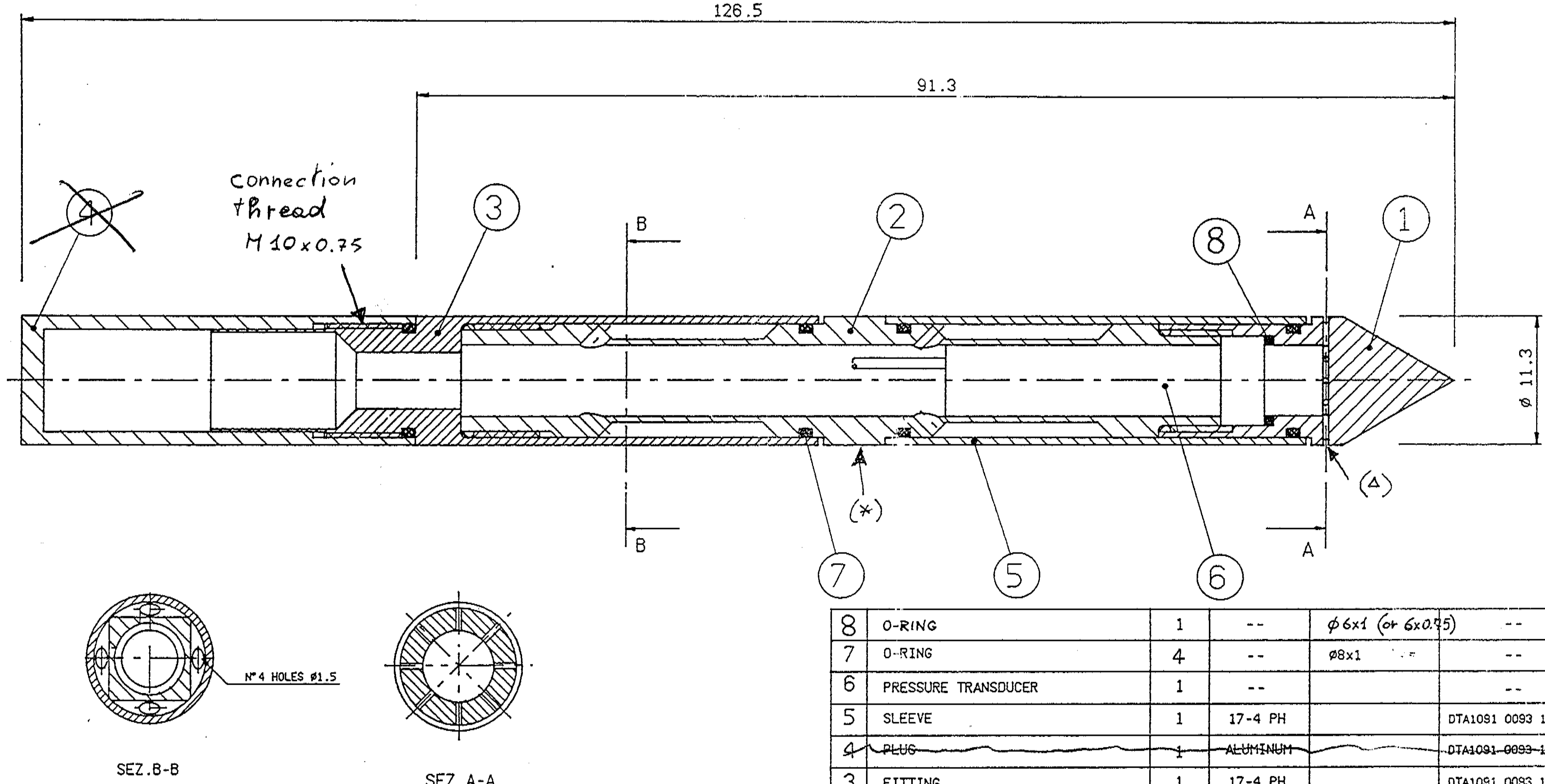
Appendix A Mini penetrometer, documents submitted by ISMES.

Appendix with documents submitted by ISMES on a min penetrometer. Total of 10 pages (excluding this).



NOTE: • for the disassembly of the tip, hold the body ② on the surface (*) and unscrew Tip ①.
During this operation, the transducer ⑥ may rotate, so, allow it's cable to rotate, too.

• For a correct pressure measurement:
- make a filter using a cotton wire wound around (Δ),
- saturate tip and filter in silicon oil,
- durig flight, maintain the tip under water.

POS	title	pieces n°	material	note	drawing n°
8	O-RING	1	--	ø 6x1 (or 6x0.75)	--
7	O-RING	4	--	ø8x1	--
6	PRESSURE TRANSDUCER	1	--		--
5	SLEEVE	1	17-4 PH		DTA1091 0093 117 06
~~4~~	~~PLUG~~	~~1~~	~~ALUMINUM~~		~~DTA1091 0093 117 05~~
3	FITTING	1	17-4 PH		DTA1091 0093 117 04
2	INSTRUMENTED BODY	1	17-4 PH		DTA1091 0093 117 03
1	TIP 'B'	1	17-4 PH		DTA1091 0093 117 01

TITLE
MINI-PENETROMETER

scale 2:1 | date 15-10-91
drawing n° DTA1091 0093 117 00 | REV. 00

ISMES
tecn.CAD R.VEDOVELLI
chek.
approv.

Viale G.Cesare, 29 - BERGAMO

ISMES S.p.A.-V.le Giulio Cesare,29 24100 BERGAMO-Tel.035 307111,Fax.307710
Summary sheet of transducers series : MN8_1

Minimum Square Root method

Transducer	: TIP	S/N	: 8
Manufacturer	: ISMES	Type	: Minicone
Range	: 0.0 /1000.0	N	
sensitivity	: 0.000319341	mV/V/N	
Error bandwidth < =	: 0.3200	% Full range	

Minimum Square Root method

Transducer	: TIP +Friction	S/N	: 8
Manufacturer	: ISMES	Type	: Minicone
Range	: 0.0 /1000.0	N	
sensitivity	: 0.000320818	mV/V/N	
Error bandwidth < =	: 0.6701	% Full range	

Minimum Square Root method

Transducer	: Piezometer	S/N	: 8
Manufacturer	: ISMES	Type	: Minicone
Range	: 0.0 /35.0	Kg/cm^2	
sensitivity	: 0.175172024	mV/V/Kg/cm^2	
sensitivity	: 1.786754643	mV/V/MPa	
Error bandwidth < =	: 0.4327	% Full range	

Operator ———— Responsible ———— Date mm/dd/yy : 07/13/94

ISMES - BERGAMO

Divisione Geotecnica

Calibration chart number : MN8_1 Minimum square root method

Transducer	: TIP		S/N	: 8
Manufacturer	: ISMES		Type	: Minicone
Range	: 0.0 /1000.00 N		Area	: 0.78 cm^2
Preload Value	:		Total Area	: 1.00 cm^2

Test conditions

Excitation bridge	: 5.0 Vdc		Frequency	: 0.00 Hz
Gain	: 1.0		Temperature	: 20.0 |C

Unit N	Readout values mV/V									
	Step n. 1 I	Step n. 1 D	Step n. 2 I	Step n. 2 D	Step n. 3 I	Step n. 3 D	Values L.S.L.	max Err. +	max Err. -	Rel. Err. %
0.0000	0.00000	0.00000	0.00000	0.00000			0.00031	0.00000	-0.00031	100.000
100.0000	0.03200	0.03200	0.03200	0.03200			0.03224	0.00000	-0.00024	0.747
200.0000	0.06400	0.06400	0.06400	0.06400			0.06418	0.00000	-0.00018	0.273
300.0000	0.09600	0.09700	0.09600	0.09700			0.09611	0.00089	-0.00011	0.927
400.0000	0.12800	0.12800	0.12800	0.12900			0.12804	0.00096	-0.00004	0.747
500.0000	0.16000	0.16100	0.16000	0.16000			0.15998	0.00102	0.00000	0.639
600.0000	0.19200	0.19200	0.19200	0.19200			0.19191	0.00009	0.00000	0.046
700.0000	0.22400	0.22400	0.22400	0.22400			0.22385	0.00015	0.00000	0.069
800.0000	0.25600	0.25600	0.25600	0.25600			0.25578	0.00022	0.00000	0.086
900.0000	0.28800	0.28800	0.28700	0.28800			0.28771	0.00029	-0.00071	0.248
1000.0000	0.31900	0.31900	0.31900	0.31900			0.31965	0.00000	-0.00065	0.203

Error bandwith limits : 0.00102 -0.00071

Measured values

Load = 0.0000 N : 0.00000 mV/V
Load = 1000.0000 N : 0.31900 mV/V

Computed values

Load = 0.0000 N : 0.00031 mV/V
Load = 1000.0000 N : 0.31965 mV/V
Offset = : 0.00031 mV/V

Sensitivity : 0.000319341 mV/V/N

Error bandwith < = : 0.3200 % Full range

Operator________________ Responsible________________ Date mm/dd/yy : 07/13/94

ISMES - BERGAMO

Divisione Geotecnica

Calibration chart number : MN8_1 Minimum square root method

Transducer : TIP +Friction
Manufacturer : ISMES
Range : 0.0 /1000.00 N
Preload Value :

S/N : 8
Type : Minicone
Area : 15.00 cm^2
Total Area : 15.00 cm^2

Test conditions

Excitation bridge : 5.0 Vdc
Gain : 1.0

Frequency : 0.00 Hz
Temperature: 20.0 |C

Unit N	Readout values mV/V									
	Step n. 1 I	Step n. 1 D	Step n. 2 I	Step n. 2 D	Step n. 3 I	Step n. 3 D	Values L.S.L.	max Err. +	max Err. -	Rel. Err. %
0.0000	0.00000	0.00000	0.00000	0.00000			-0.00064	0.00064	0.00000	100.000
100.0000	0.03100	0.03200	0.03000	0.03100			0.03145	0.00055	-0.00145	4.597
200.0000	0.06300	0.06400	0.06200	0.06300			0.06353	0.00047	-0.00153	2.404
300.0000	0.09500	0.09700	0.09400	0.09600			0.09561	0.00139	-0.00161	1.683
400.0000	0.12700	0.12900	0.12600	0.12800			0.12769	0.00131	-0.00169	1.324
500.0000	0.15900	0.16100	0.15800	0.16000			0.15977	0.00123	-0.00177	1.110
600.0000	0.19200	0.19400	0.19100	0.19300			0.19185	0.00215	-0.00085	1.118
700.0000	0.22400	0.22600	0.22300	0.22500			0.22394	0.00206	-0.00094	0.922
800.0000	0.25600	0.25800	0.25500	0.25700			0.25602	0.00198	-0.00102	0.774
900.0000	0.28800	0.28900	0.28700	0.28800			0.28810	0.00090	-0.00110	0.382
1000.0000	0.32000	0.32000	0.31900	0.31900			0.32018	0.00000	-0.00118	0.369

Error bandwith limits : 0.00215 -0.00177

Measured values

Load = 0.0000 N : 0.00000 mV/V
Load = 1000.0000 N : 0.31950 mV/V

Computed values

Load = 0.0000 N : -0.00064 mV/V
Load = 1000.0000 N : 0.32018 mV/V
Offset = : -0.00064 mV/V

Sensitivity : 0.000320818 mV/V/N

Error bandwith < = : 0.6701 % Full range

Operator_________________ Responsible_______________ Date mm/dd/yy : 07/13/94

ISMES - BERGAMO

Divisione Geotecnica

Calibration chart number : MN8_1 Minimum square root method

Transducer	: Piezometer	S/N	: 8
Manufacturer	: ISMES	Type	: Minicone
Range	: 0.0 /35.00 Kg/cm^2	Area	: 0.00 cm^2
Preload Value	:	Total Area	:

Test conditions

Excitation bridge	: 5.0 Vdc	Frequency	: 0.00 Hz
Gain	: 1.0	Temperature:	20.0 |C

Unit Kg/cm^2	Readout values mV/V									
	Step n. 1		Step n. 2		Step n. 3		Values	max Err.		Rel. Err.
	I	D	I	D	I	D	L.S.L.	+	-	%
0.0000	0.00000	0.00000	0.00000	0.00000			0.02665	0.00000	-0.02665	100.000
5.0000	0.91600	0.91600	0.91600	0.91600			0.90251	0.01349	0.00000	1.495
10.0000	1.78900	1.79000	1.78900	1.79000			1.77837	0.01163	0.00000	0.654
15.0000	2.66300	2.66400	2.66300	2.66400			2.65423	0.00977	0.00000	0.368
20.0000	3.53500	3.53600	3.53500	3.53600			3.53009	0.00591	0.00000	0.168
25.0000	4.40600	4.40700	4.40600	4.40700			4.40595	0.00105	0.00000	0.024
30.0000	5.27700	5.27800	5.27700	5.27700			5.28181	0.00000	-0.00481	0.091
35.0000	6.14900	6.14900	6.14900	6.14900			6.15767	0.00000	-0.00867	0.141

Error bandwith limits : 0.01349 -0.02665

Measured values

Load = 0.0000 Kg/cm^2 : 0.00000 mV/V
Load = 35.0000 Kg/cm^2 : 6.14900 mV/V

Computed values

Load = 0.0000 Kg/cm^2 : 0.02665 mV/V
Load = 35.0000 Kg/cm^2 : 6.15767 mV/V
Offset = : 0.02665 mV/V

Sensitivity : 0.175172024 mV/V/Kg/cm^2
Sensitivity : 1.786754643 mV/V/MPa

Error bandwith < = : 0.4327 % Full range

Operator__________________Responsible________________ Date mm/dd/yy : 07/13/94

ISMES S.p.A.-V.le Giulio Cesare,29 24100 BERGAMO-Tel.035 307111,Fax.307710
Summary sheet of transducers series : MN8_2

Minimum Square Root method

Transducer	: TIP	S/N	: 8
Manufacturer	: ISMES	Type	: Minicone
Range	: 0.0 /10000.0	N	
sensitivity	: 0.000317125	mV/V/N	
Error bandwidth < =	: 0.1788	% Full range	

Minimum Square Root method

Transducer	: TIP +Friction	S/N	: 8
Manufacturer	: ISMES	Type	: Minicone
Range	: 0.0 /10000.0	N	
sensitivity	: 0.000318547	mV/V/N	
Error bandwidth < =	: 0.1910	% Full range	

Minimum Square Root method

Transducer	: Piezometer	S/N	: 8
Manufacturer	: ISMES	Type	: Minicone
Range	: 0.0 /35.0	Kg/cm^2	
sensitivity	: 0.175172024	mV/V/Kg/cm^2	
sensitivity	: 1.786754643	mV/V/MPa	
Error bandwidth < =	: 0.4327	% Full range	

Operator ———— Responsible ———— Date mm/dd/yy : 07/13/94

ISMES - BERGAMO

Divisione Geotecnica

Calibration chart number : MN8_2 Minimum square root method

Transducer : TIP
Manufacturer : ISMES
Range : 0.0 /10000.00 N
Preload Value :

S/N : 8
Type : Minicone
Area : 0.78 cm^2
Total Area : 1.00 cm^2

Test conditions

Excitation bridge : 5.0 Vdc
Gain : 1.0

Frequency : 0.00 Hz
Temperature: 20.0 |C

Unit N	Readout values mV/V									
	Step n. 1		Step n. 2		Step n. 3		Values	max Err.		Rel. Err.
	I	D	I	D	I	D	L.S.L.	+	-	%
0.0000	0.00000	0.00000	0.00000	0.00000			0.00543	0.00000	-0.00543	100.000
1001.0000	0.31900	0.32000	0.31900	0.32100			0.32287	0.00000	-0.00387	1.200
2001.0000	0.63900	0.64000	0.63900	0.64100			0.64000	0.00100	-0.00100	0.156
3000.0000	0.95900	0.96000	0.95900	0.96000			0.95681	0.00319	0.00000	0.334
4000.0000	1.27700	1.27800	1.27800	1.27900			1.27393	0.00507	0.00000	0.398
5000.0000	1.59500	1.59600	1.59500	1.59600			1.59106	0.00494	0.00000	0.311
6000.0000	1.91200	1.91200	1.91200	1.91200			1.90818	0.00382	0.00000	0.200
7000.0000	2.22700	2.22700	2.22800	2.22800			2.22531	0.00269	0.00000	0.121
8000.0000	2.54200	2.54200	2.54300	2.54200			2.54243	0.00057	-0.00043	0.022
9000.0000	2.85700	2.85600	2.85800	2.85700			2.85955	0.00000	-0.00355	0.124
10000.0000	3.17100	3.17100	3.17100	3.17100			3.17668	0.00000	-0.00568	0.179

Error bandwith limits : 0.00507 -0.00568

Measured values

Load = 0.0000 N : 0.00000 mV/V
Load = 10000.0000 N : 3.17100 mV/V

Computed values

Load = 0.0000 N : 0.00543 mV/V
Load = 10000.0000 N : 3.17668 mV/V
Offset = : 0.00543 mV/V

Sensitivity : 0.000317125 mV/V/N

Error bandwith < = : 0.1788 % Full range

Operator________________ Responsible______________ Date mm/dd/yy : 07/13/94

ISMES - BERGAMO

Divisione Geotecnica

Calibration chart number : MN8_2 Minimum square root method

Transducer : TIP +Friction
Manufacturer : ISMES
Range : 0.0 /10000.00 N
Preload Value :

S/N : 8
Type : Minicone
Area : 15.00 cm^2
Total Area : 15.00 cm^2

Test conditions

Excitation bridge : 5.0 Vdc
Gain : 1.0

Frequency : 0.00 Hz
Temperature: 20.0 |C

Unit N	Readout values mV/V									
	Step n. 1 I	Step n. 1 D	Step n. 2 I	Step n. 2 D	Step n. 3 I	Step n. 3 D	Values L.S.L.	max Err. +	max Err. -	Rel. Err. %
0.0000	0.00000	0.00000	0.00000	0.00000			0.00261	0.00000	-0.00261	100.000
1001.0000	0.31800	0.31800	0.31800	0.31800			0.32148	0.00000	-0.00348	1.082
2001.0000	0.63800	0.63900	0.63800	0.63900			0.64003	0.00000	-0.00203	0.317
3000.0000	0.95900	0.96100	0.95900	0.96000			0.95826	0.00274	0.00000	0.286
4000.0000	1.27900	1.28000	1.27900	1.28000			1.27680	0.00320	0.00000	0.250
5000.0000	1.59900	1.60000	1.59900	1.60000			1.59535	0.00465	0.00000	0.291
6000.0000	1.91700	1.91800	1.91700	1.91800			1.91390	0.00410	0.00000	0.214
7000.0000	2.23400	2.23600	2.23400	2.23600			2.23245	0.00355	0.00000	0.159
8000.0000	2.55100	2.55300	2.55100	2.55300			2.55099	0.00201	0.00000	0.079
9000.0000	2.86700	2.86900	2.86700	2.86800			2.86954	0.00000	-0.00254	0.089
10000.0000	3.18200	3.18200	3.18200	3.18200			3.18809	0.00000	-0.00609	0.191

Error bandwith limits : 0.00465 -0.00609

Measured values

Load = 0.0000 N : 0.00000 mV/V
Load = 10000.0000 N : 3.18200 mV/V

Computed values

Load = 0.0000 N : 0.00261 mV/V
Load = 10000.0000 N : 3.18809 mV/V
Offset = : 0.00261 mV/V

Sensitivity : 0.000318547 mV/V/N

Error bandwith < = : 0.1910 % Full range

Operator________________ Responsible________________ Date mm/dd/yy : 07/13/94

ISMES - BERGAMO

Divisione Geotecnica

Calibration chart number : MN8_2 Minimum square root method

Transducer : Piezometer
Manufacturer : ISMES
Range : 0.0 /35.00 Kg/cm^2
Preload Value :

S/N : 8
Type : Minicone
Area : 0.00 cm^2
Total Area :

Test conditions

Excitation bridge : 5.0 Vdc
Gain : 1.0

Frequency : 0.00 Hz
Temperature: 20.0 |C

Unit Kg/cm^2	Readout values mV/V									
	Step n. 1		Step n. 2		Step n. 3		Values	max Err.		Rel. Err.
	I	D	I	D	I	D	L.S.L.	+	-	%
0.0000	0.00000	0.00000	0.00000	0.00000			0.02665	0.00000	-0.02665	100.000
5.0000	0.91600	0.91600	0.91600	0.91600			0.90251	0.01349	0.00000	1.495
10.0000	1.78900	1.79000	1.78900	1.79000			1.77837	0.01163	0.00000	0.654
15.0000	2.66300	2.66400	2.66300	2.66400			2.65423	0.00977	0.00000	0.368
20.0000	3.53500	3.53600	3.53500	3.53600			3.53009	0.00591	0.00000	0.168
25.0000	4.40600	4.40700	4.40600	4.40700			4.40595	0.00105	0.00000	0.024
30.0000	5.27700	5.27800	5.27700	5.27700			5.28181	0.00000	-0.00481	0.091
35.0000	6.14900	6.14900	6.14900	6.14900			6.15767	0.00000	-0.00867	0.141

Error bandwith limits : 0.01349 -0.02665

Measured values

Load = 0.0000 Kg/cm^2 : 0.00000 mV/V
Load = 35.0000 Kg/cm^2 : 6.14900 mV/V

Computed values

Load = 0.0000 Kg/cm^2 : 0.02665 mV/V
Load = 35.0000 Kg/cm^2 : 6.15767 mV/V
Offset = : 0.02665 mV/V

Sensitivity : 0.175172024 mV/V/Kg/cm^2
Sensitivity : 1.786754643 mV/V/MPa

Error bandwith < = : 0.4327 % Full range

Operator________________ Responsible________________ Date mm/dd/yy : 07/13/94

WIRING DIAGRAM			
	TIP	*TIP+FRICTION*	*PORE PRESS.*
IN +	RED	RED	RED
IN -	YELLOW	YELLOW	BLU
OUT +	BLU	BLU	YELLOW
OUT -	GREEN	GREEN	GREEN

Appendix B   Results from lateral load tests.

Appendix with results from lateral load tests. Total of 53 pages (excluding this).

Summary of lateral load tests

Date	User*	Test type	Diameter (D)	Setup Embedment length (L)	Load height (e)	Scaling (N-ref)	Void ratio	Note
05-03-2008	CTL	Static	16 mm	24,25 D	2,5 D	57,5	0,614	1)
10-03-2008	CTL	Static	16 mm	11,875 D	2,5 D	56,4	0,591	
12-03-2008	CTL	Static	16 mm	11,875 D	2,5 D	56,6	0,585	
17-03-2008	CTL	Static	16 mm	6 D	2,5 D	62,0	0,585	
01-04-2008	CTL	Static	16 mm	6 D	2,5 D	61,6	0,602	
22-04-2008	CTL	Static	16 mm	8 D	2,5 D	61,5	0,600	
24-04-2008	CTL	Static	16 mm	8 D	2,5 D	61,6	0,585	2)
29-04-2008	CTL	Static	16 mm	10 D	2,5 D	61,2	0,589	
30-04-2008	CTL	Static	28 mm	6 D	1,429 D	69,8	0,598	
05-06-2008	CTL	Static	28 mm	8 D	1,429 D	69,9	0,599	
12-06-2008	CTL	Static	28 mm	10 D	1,429 D	69,1	0,613	
23-10-2008	RAKLI	Static	16 mm	6 D	4,5 D	64,7	0,575	5) 6)
24-10-2008	RAKLI	Static	16 mm	8 D	4,5 D	63,8	0,567	5) 6)
24-10-2008	RAKLI	Static	16 mm	6 D	6,5 D	63,9	0,571	5) 6)
08-11-2008	RAKLI	Cyclic	16 mm	10 D	2,5 D	60,6	0,572	6)
10-11-2008	RAKLI	Cyclic	16 mm	6 D	2,5 D	60,6	0,570	6)
10-11-2008	RAKLI	Cyclic	16 mm	8 D	2,5 D	60,3	0,576	6)
12-11-2008	RAKLI	Cyclic	16 mm	8 D	4,5 D	60,4	0,566	6)
17-11-2008	RAKLI	Cyclic	16 mm	6 D	4,5 D	60,6	0,574	6)
20-11-2008	RAKLI	Cyclic	16 mm	6 D	6,5 D	60,6	0,562	6)
15-04-2009	CTL	Static	16 mm	8 D	4,5 D	60,8	0,598	
22-04-2009	CTL	Cyclic	28 mm	6 D	1,429 D	69,4	0,601	
23-04-2009	CTL	Cyclic	28 mm	8 D	1,429 D	68,9	0,606	
23-04-2009	CTL	Cyclic	28 mm	10 D	1,429 D	68,4	0,607	
27-04-2009	CTL	Static	40 mm	6 D	1 D	72,3	0,595	3)
28-04-2009	CTL	Cyclic	16 mm	10 D	2,5 D	60,9	0,604	
28-04-2009	CTL	Cyclic	16 mm	8 D	2,5 D	61,2	0,602	
29-04-2009	CTL	Cyclic	16 mm	6 D	2,5 D	61,5	0,596	
30-04-2009	CTL	Cyclic	28 mm	6 D	1,429 D	69,5	0,591	
15-05-2009	RAKLI	Static	40 mm	6 D	1 D	72,4	0,593	4)
19-05-2009	RAKLI	Cyclic	40 mm	6 D	1 D	72,4	0,600	4)
25-05-2009	RAKLI	Static	40 mm	8 D	1 D	71,6	0,588	4)
04-06-2009	RAKLI	Cyclic	40 mm	8 D	1 D	71,6	0,584	4)
17-08-2009	RAKLI	Static	16 mm	10 D	6,5 D	61,0	0,570	5) 6)
18-08-2009	RAKLI	Static	16 mm	10 D	4,5 D	61,1	0,558	5) 6)
26-08-2009	RAKLI	Static	16 mm	8 D	6,5 D	60,6	0,598	5) 6)

** CTL is Caspar Thrane Leth and RAKLI is Rasmus Klinkvort*

1) The pile was of aluminium and was bended during testing

2) Results seems defective - too low ultimate resistance

3) Mechnical failure of setup - charnier to load transfer to pile broke

4) Reprint of results from Klinkvort (2009b)

5) Reprint of results from Klinkvort et al (20010)

6) Reprint of results from Klinkvort (2009a)

LATERAL LOAD TEST 05-03-2008

Page 1/1

Test information

Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	24,25 D
Load height (e)	2,5 D
Scale (N)	57,5

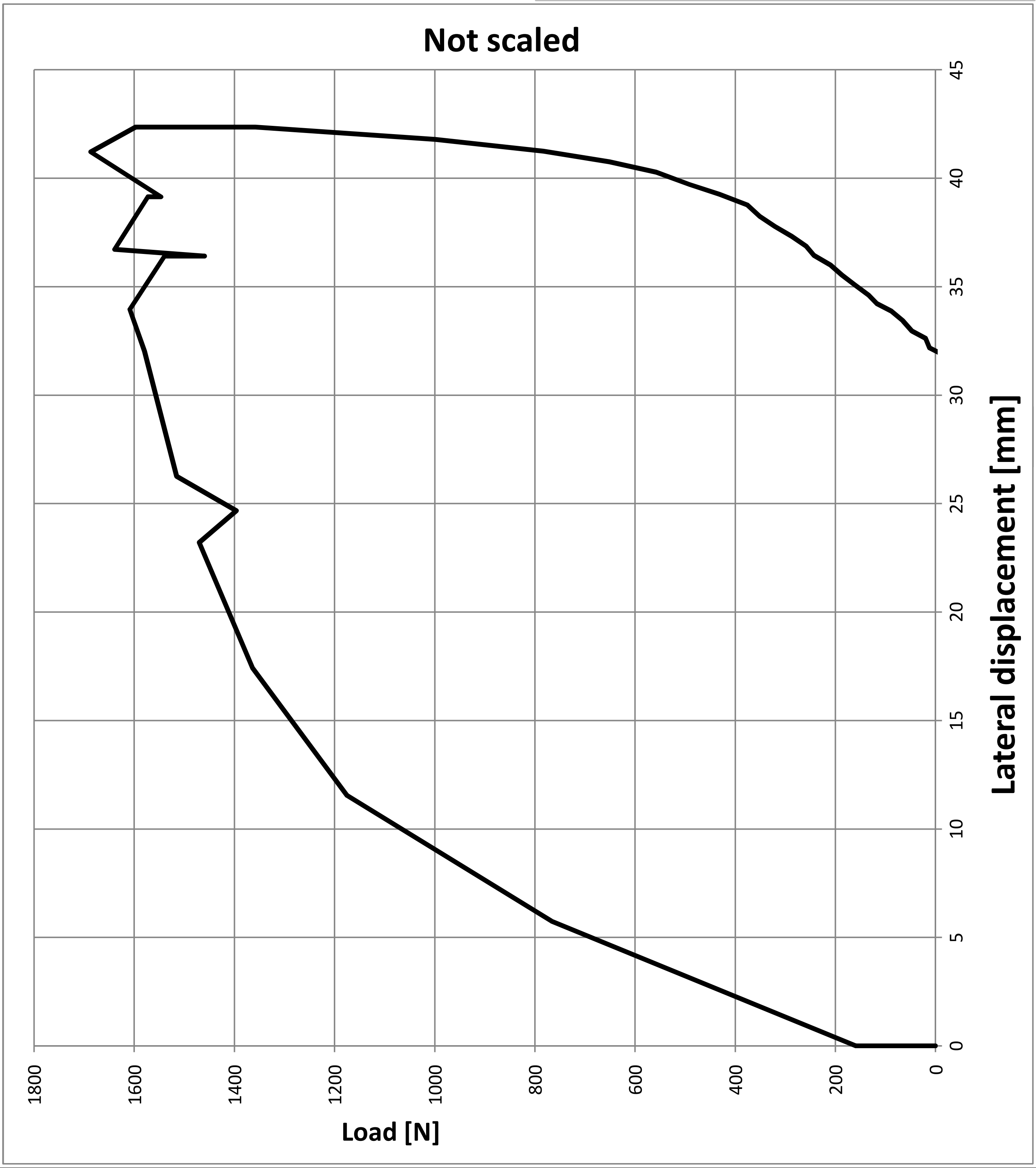
Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	03-03-2008
Density,ρ	1639,8 kg/m^3
Void ratio,e	0,614
Rel. density, Id	0,789

The pile was of aluminium and was bended during testing.



LATERAL LOAD TEST 10-03-2008

Test information

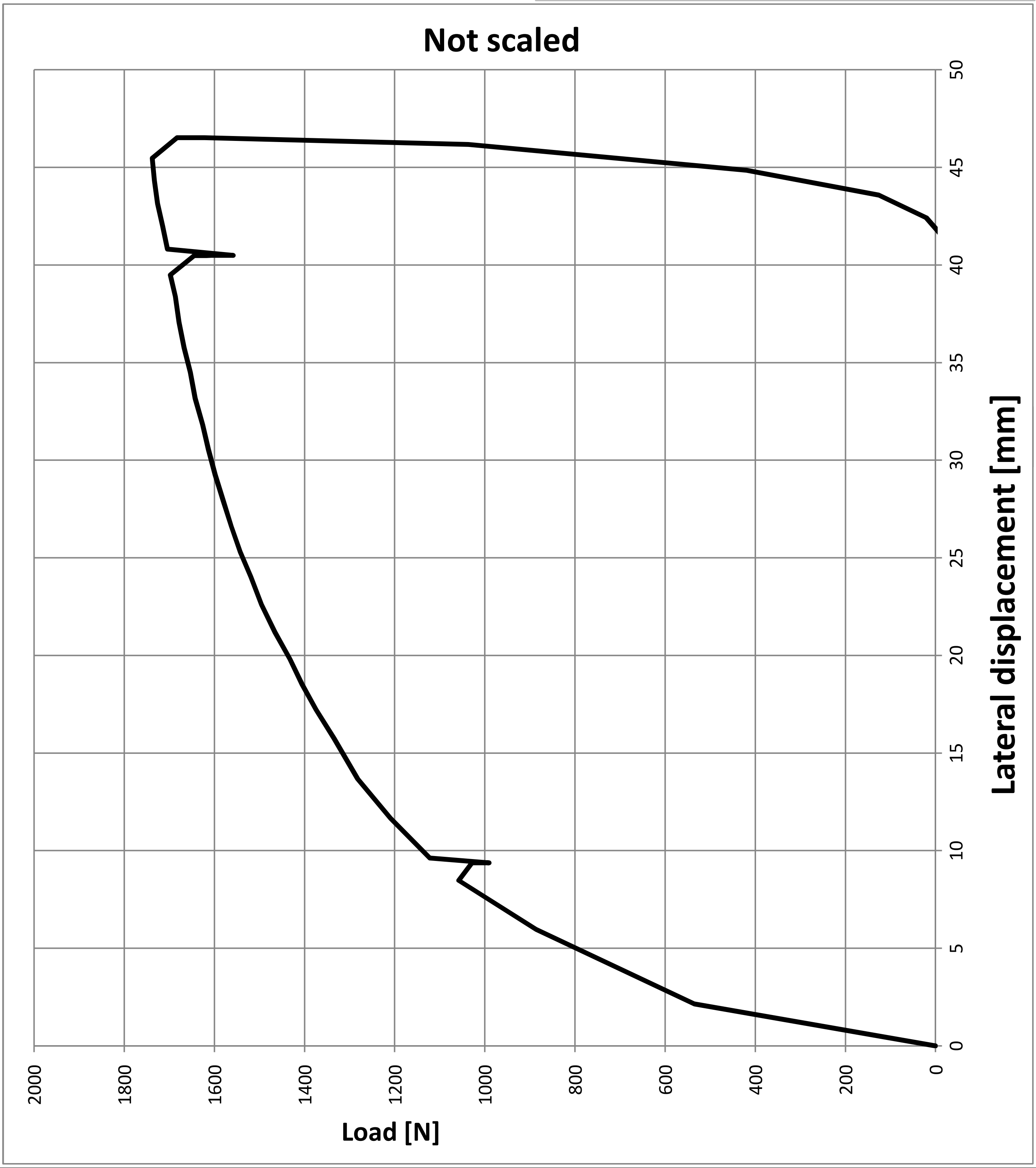
Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	11,88 D
Load height (e)	2,5 D
Scale (N)	56,4

Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	06-03-2008
Density,ρ	1663,4 kg/m^3
Void ratio,e	0,591
Rel. density, Id	0,863



LATERAL LOAD TEST 12-03-2008

Test information

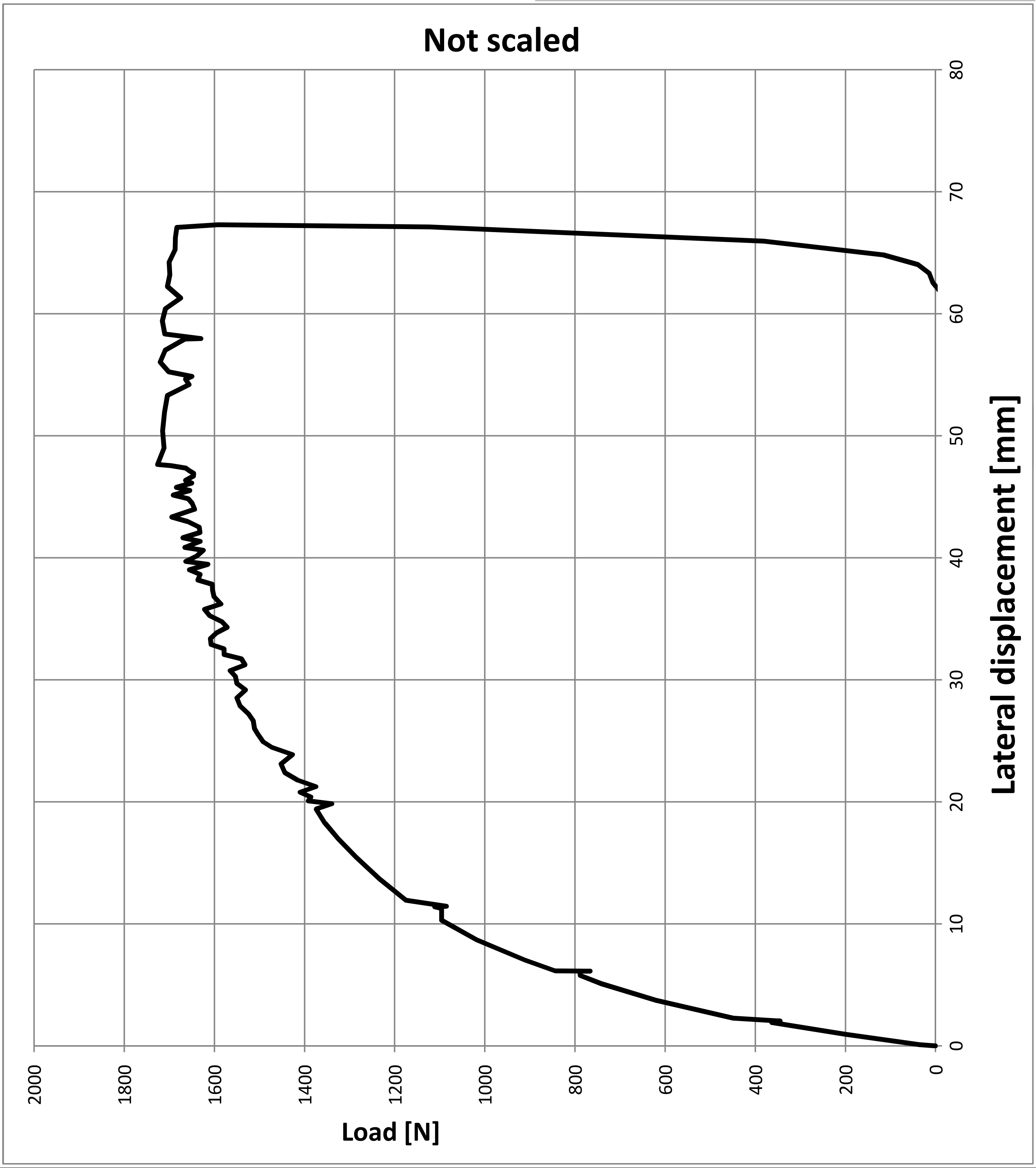
Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	11,88 D
Load height (e)	2,5 D
Scale (N)	56,6

Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	11-03-2008
Density,ρ	1669,6 kg/m^3
Void ratio,e	0,585
Rel. density, Id	0,882



LATERAL LOAD TEST 17-03-2008

Test information

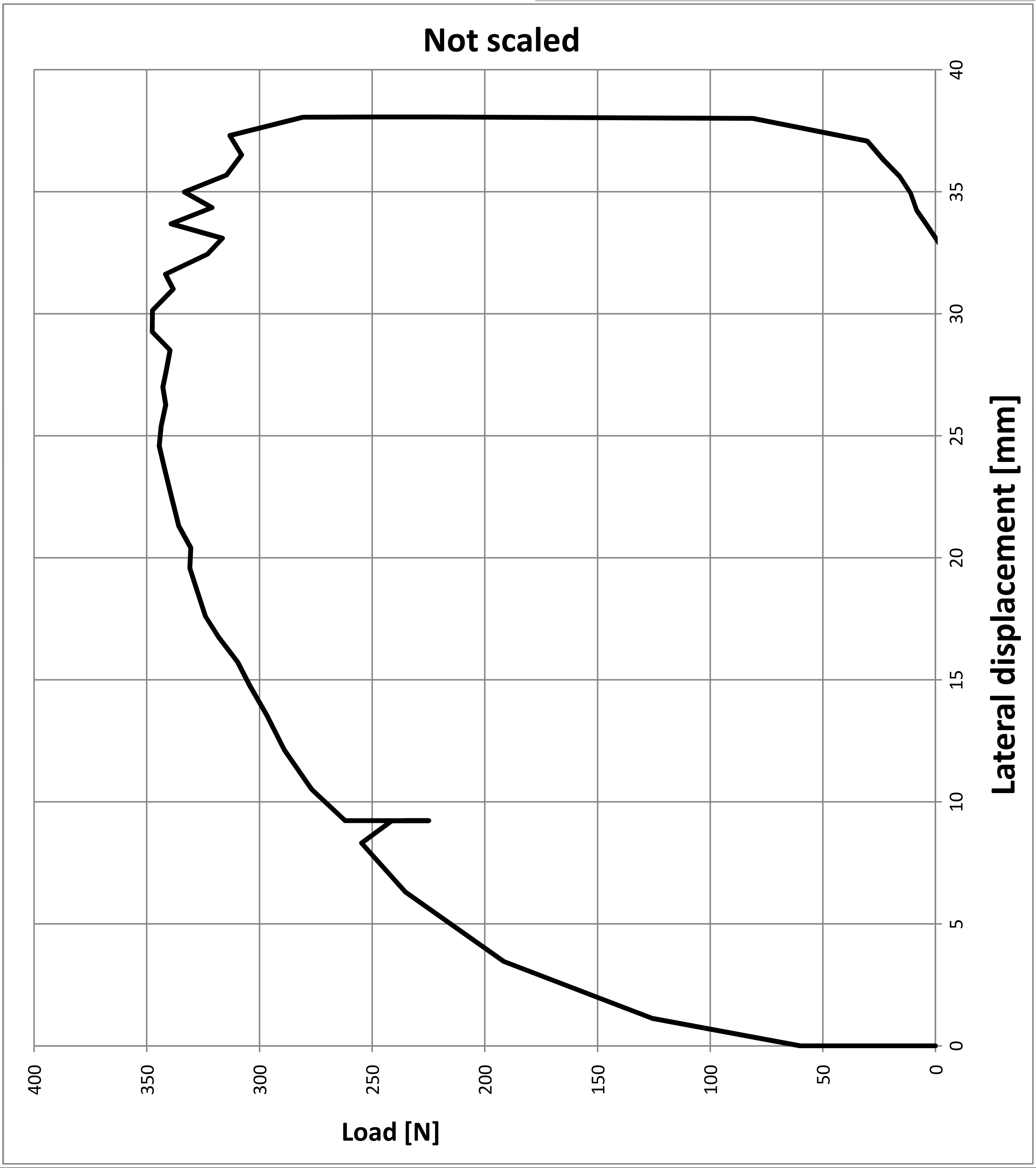
Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	6, D
Load height (e)	2,5 D
Scale (N)	62

Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	13-03-2008
Density,ρ	1669,9 kg/m^3
Void ratio,e	0,585
Rel. density, Id	0,883

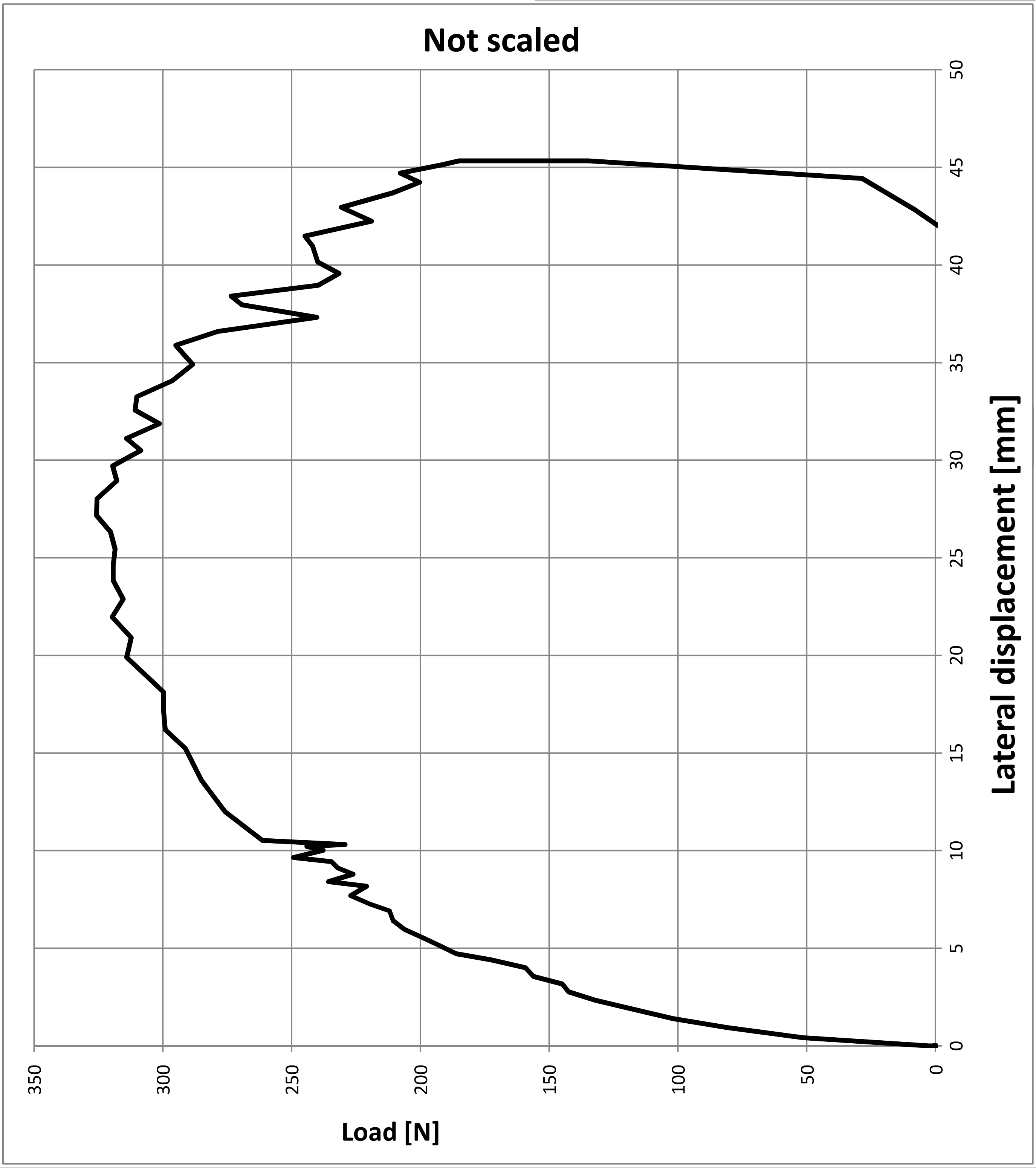


LATERAL LOAD TEST 01-04-2008

Test information		**Preparation:**	
Type	STATIC	Date:	01-04-2008
Pile diameter (D)	16 mm	Density,ρ	1651,7 kg/m^3
Embedment length (L)	6, D	Void ratio,e	0,602
Load height (e)	2,5 D	Rel. density, Id	0,826
Scale (N)	61,6		

Calibration date:

Novo100	28-02-2008
LC7	04-03-2008



LATERAL LOAD TEST 22-04-2008	Page 1/1

Test information

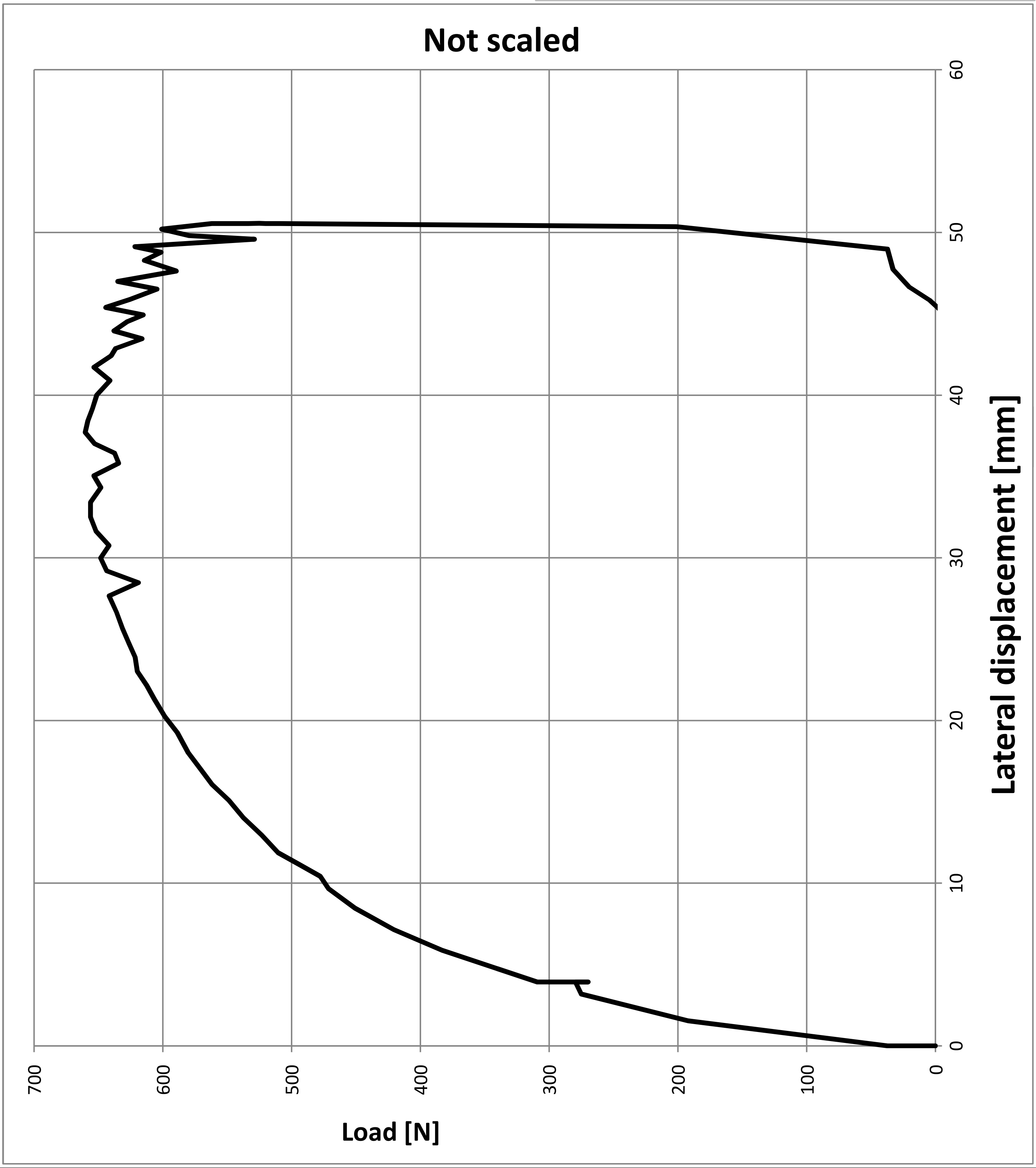
Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	8, D
Load height (e)	2,5 D
Scale (N)	61,5

Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	22-04-2008
Density,ρ	1653,4 kg/m^3
Void ratio,e	0,600
Rel. density, Id	0,832



LATERAL LOAD TEST 24-04-2008

Test information

Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	8, D
Load height (e)	2,5 D
Scale (N)	61,6

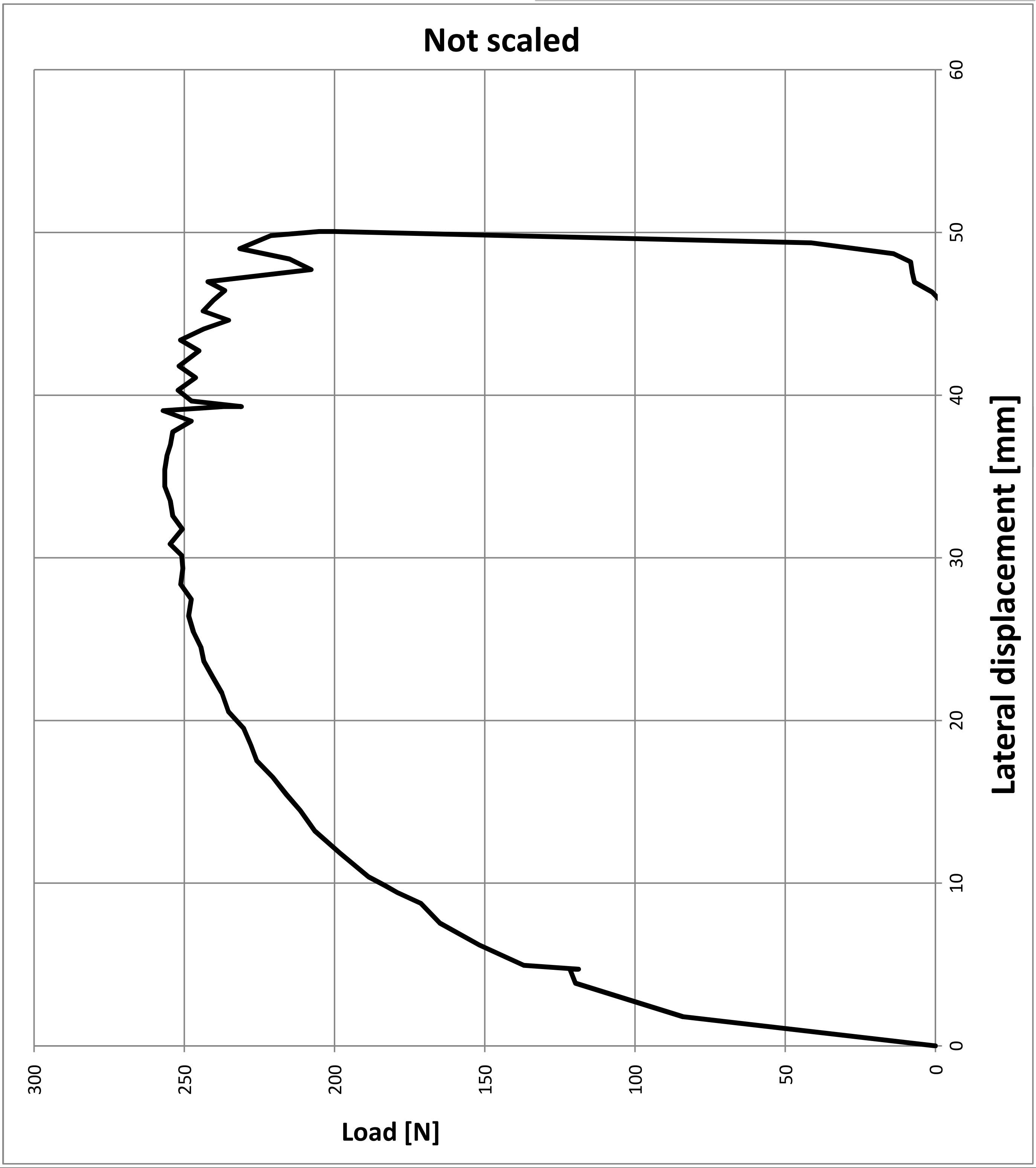
Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	23-04-2008
Density,ρ	1669,6 kg/m^3
Void ratio,e	0,585
Rel. density, Id	0,882

Result seems defective - too low ultimate resistance.



LATERAL LOAD TEST 29-04-2008

Test information

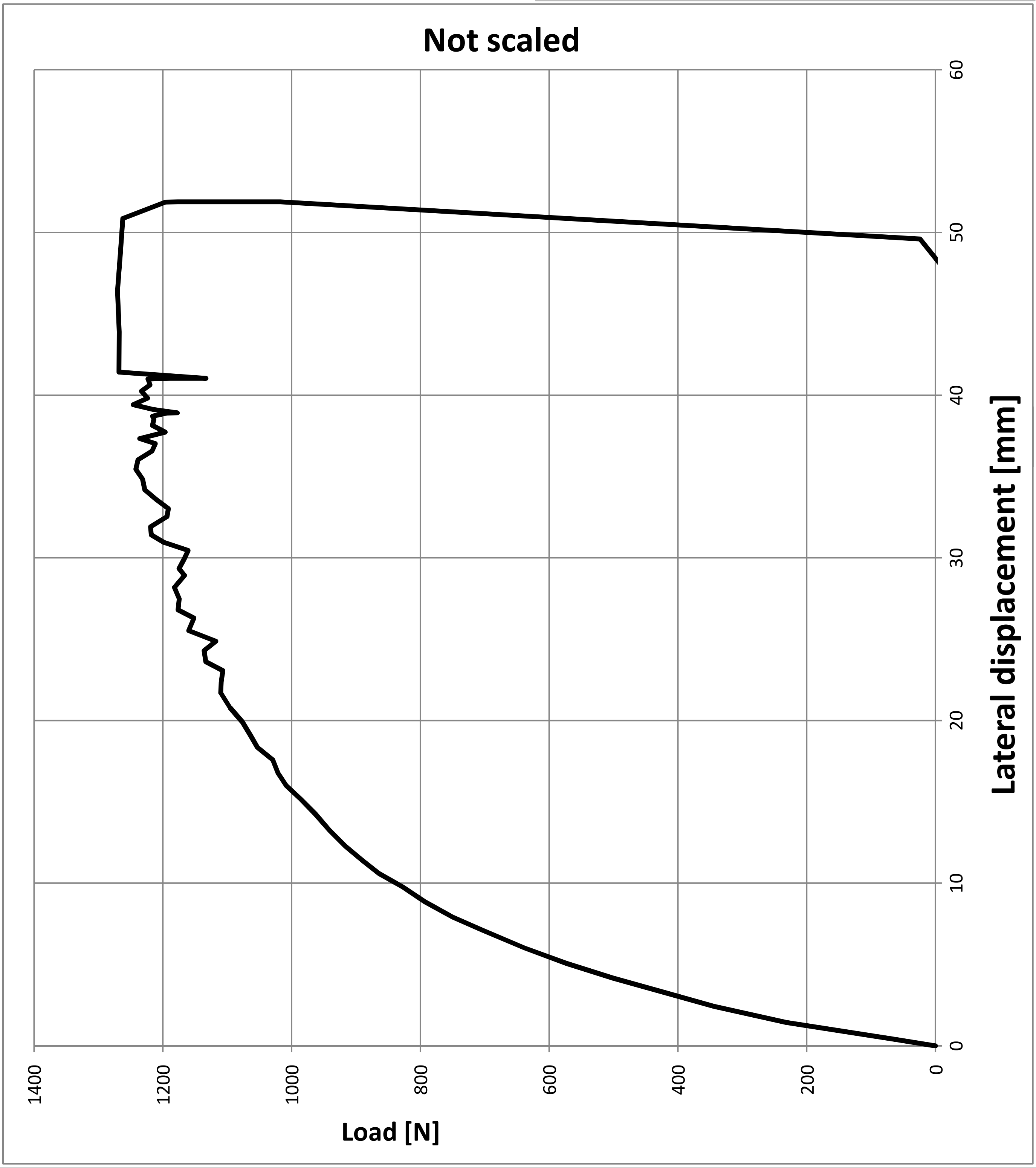
Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	10, D
Load height (e)	2,5 D
Scale (N)	61,2

Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	28-04-2008
Density,ρ	1665,7 kg/m^3
Void ratio,e	0,589
Rel. density, Id	0,87



LATERAL LOAD TEST 30-04-2008

Test information

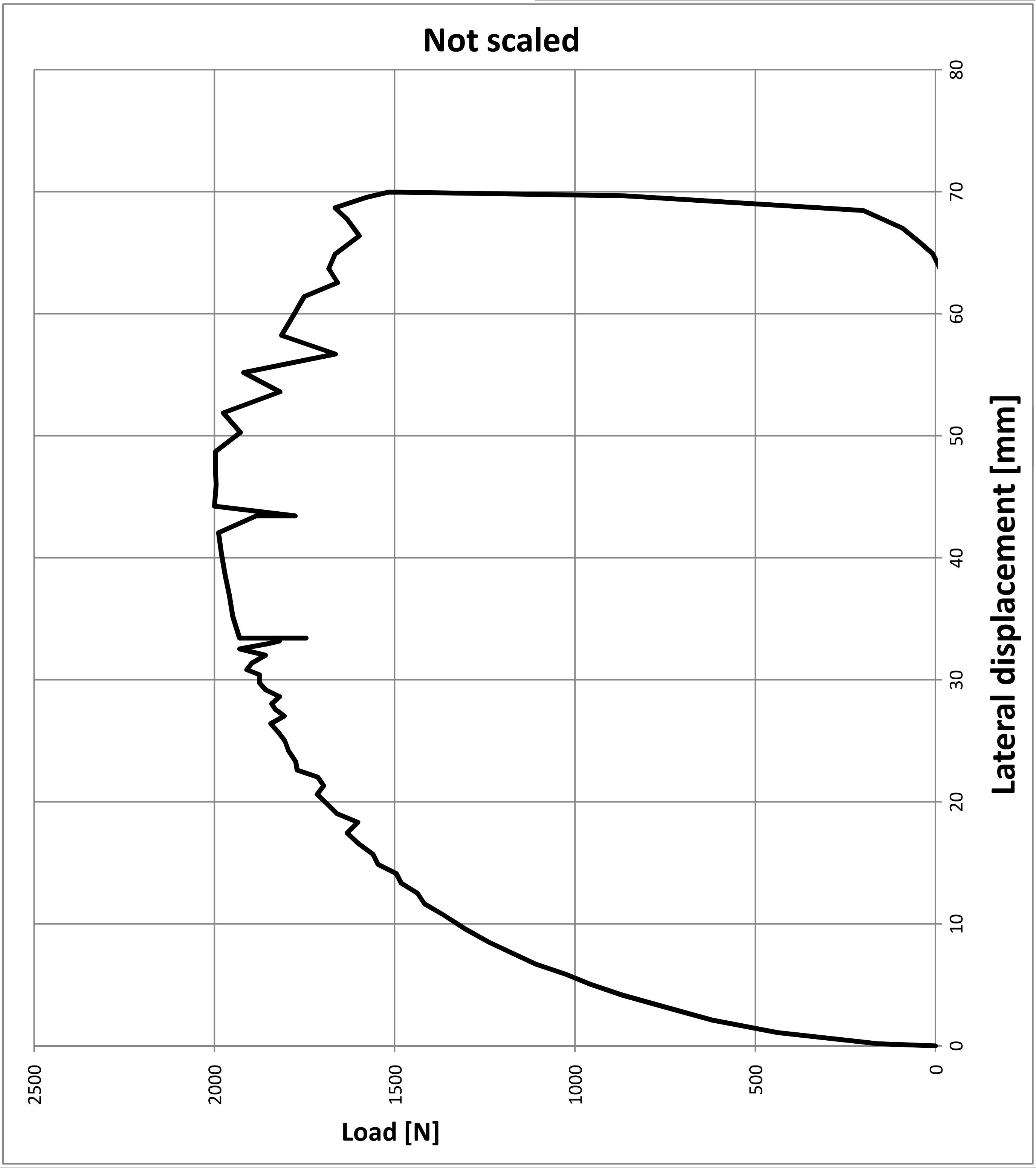
Type	STATIC
Pile diameter (D)	28 mm
Embedment length (L)	6, D
Load height (e)	1,428571429 D
Scale (N)	69,8

Calibration date:

Novo100	28-02-2008
LC7	04-03-2008

Preparation:

Date:	29-04-2008
Density,ρ	1656,1 kg/m^3
Void ratio,e	0,598
Rel. density, Id	0,84

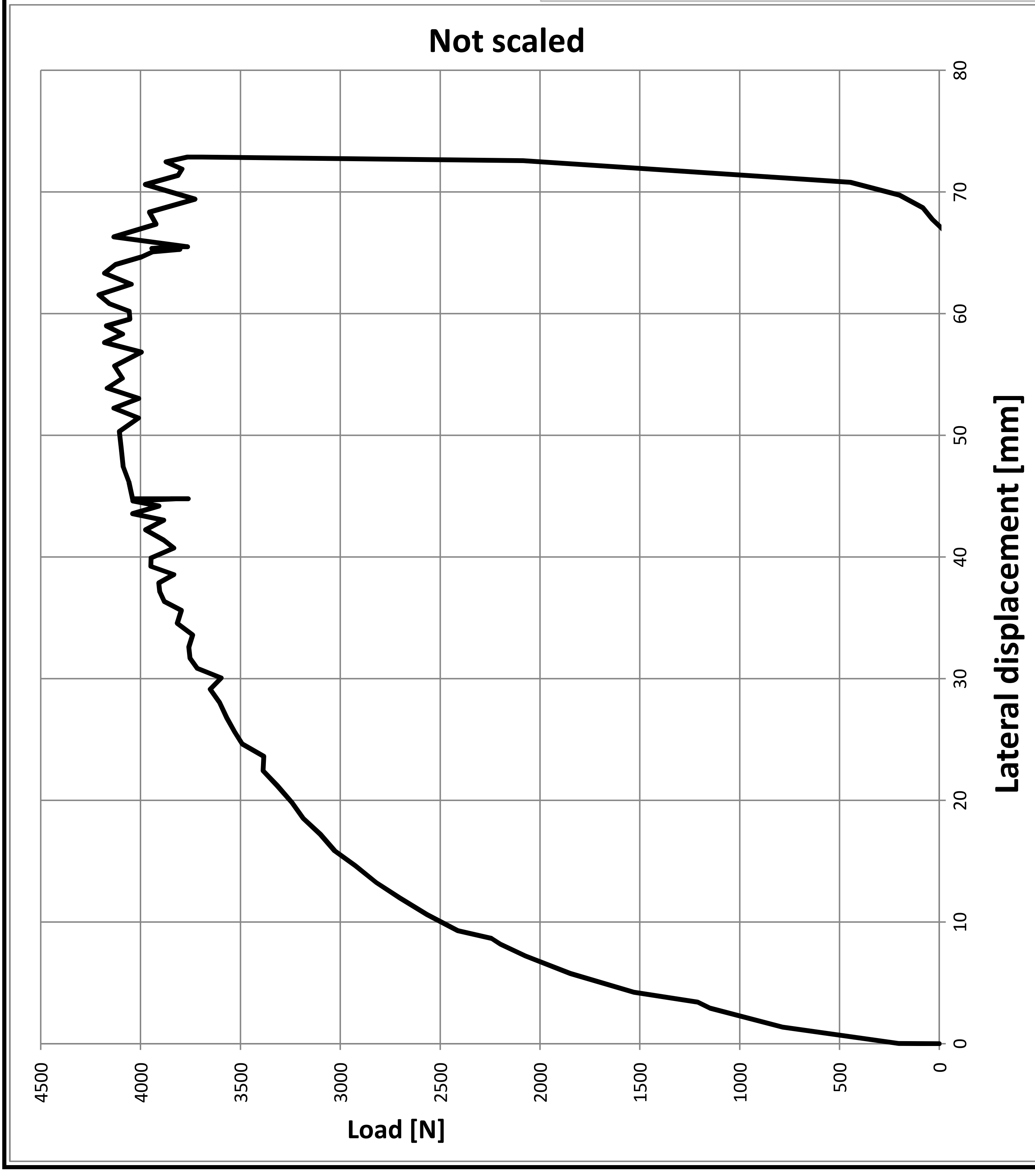


LATERAL LOAD TEST 05-06-2008

Test information		Preparation:	
Type	STATIC	Date:	04-06-2008
Pile diameter (D)	28 mm	Density,ρ	1654,6 kg/m^3
Embedment length (L)	8, D	Void ratio,e	0,599
Load height (e)	1,428571429 D	Rel. density, Id	0,835
Scale (N)	69,9		

Calibration date:

Novo100	28-02-2008
New LC	18-06-2008



LATERAL LOAD TEST 12-06-2008	Page 1/1

Test information

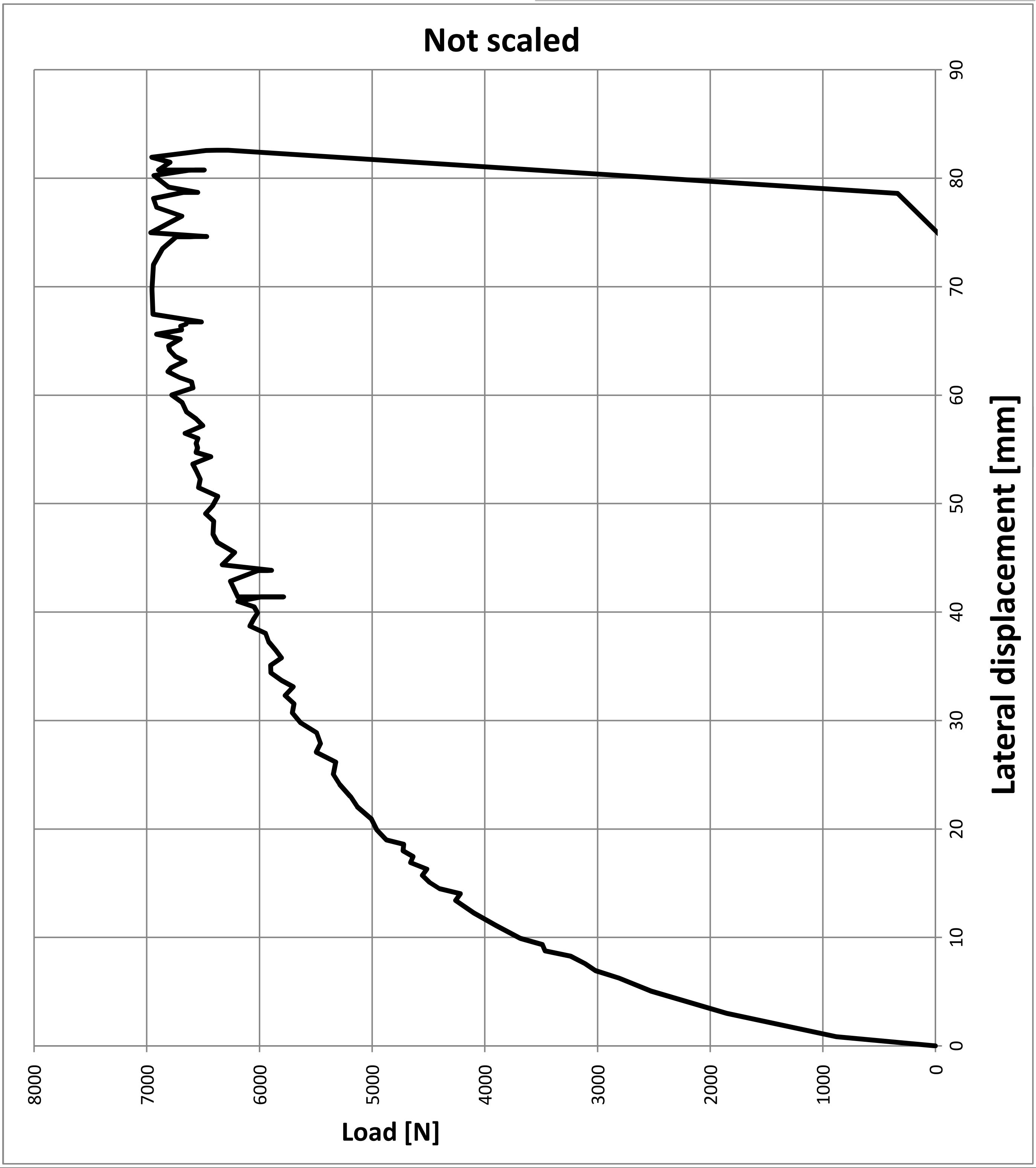
Type	STATIC
Pile diameter (D)	28 mm
Embedment length (L)	10, D
Load height (e)	1,428571429 D
Scale (N)	69,1

Calibration date:

Novo100	28-02-2008
New LC	18-06-2008

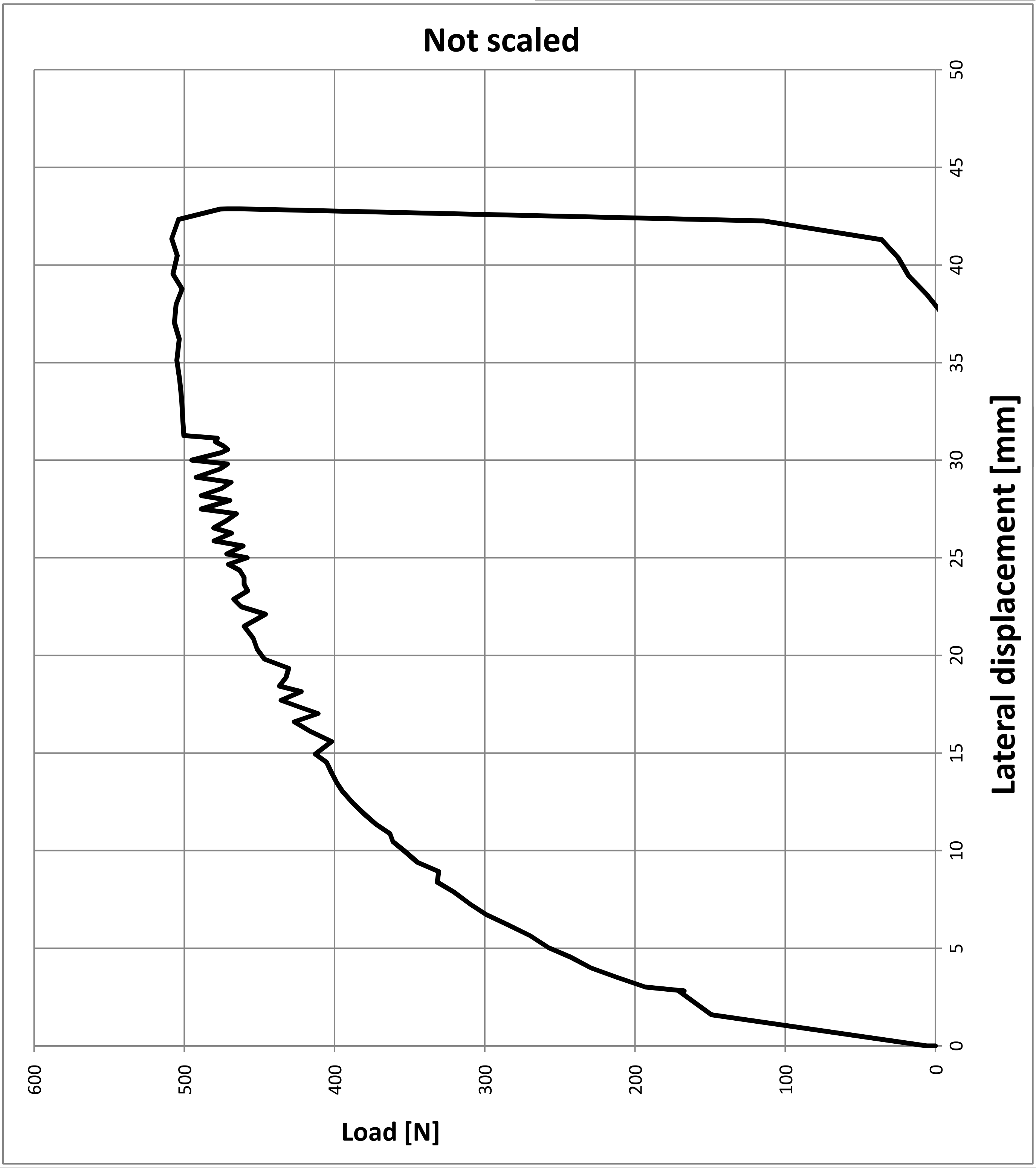
Preparation:

Date:	11-06-2008
Density,ρ	1640,2 kg/m^3
Void ratio,e	0,613
Rel. density, Id	0,79



LATERAL LOAD TEST 15-04-2009

Test information		**Preparation:**	
Type	STATIC	Date:	15-04-2009
Pile diameter (D)	16 mm	Density,ρ	1655,4 kg/m^3
Embedment length (L)	8, D	Void ratio,e	0,598
Load height (e)	4,5 D	Rel. density, Id	0,838
Scale (N)	60,8		
Calibration date:			
Novo100	28-02-2008		
LC7	17-06-2008		



LATERAL LOAD TEST 27-04-2009	Page 1/1

Test information

Type	STATIC
Pile diameter (D)	40 mm
Embedment length (L)	6, D
Load height (e)	1 D
Scale (N)	72,3

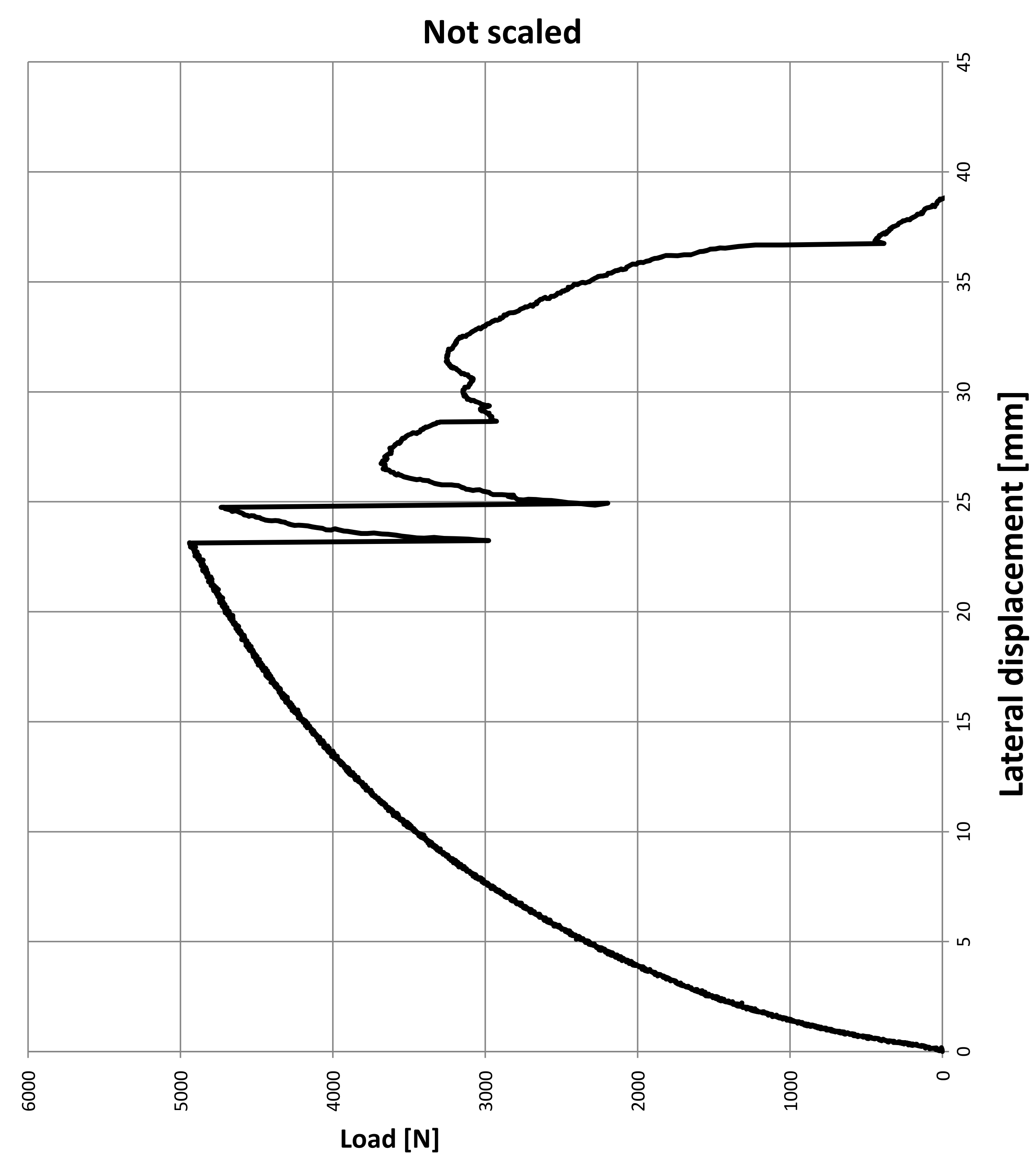
Calibration date:

Novo100	28-02-2008
New LC	30-04-2009

Preparation:

Date:	27-04-2009, 1st prep.
Density,ρ	1658,7 kg/m^3
Void ratio,e	0,595
Rel. density, Id	0,848

Mechnical failure of setup - charnier for load transfer to pile broke



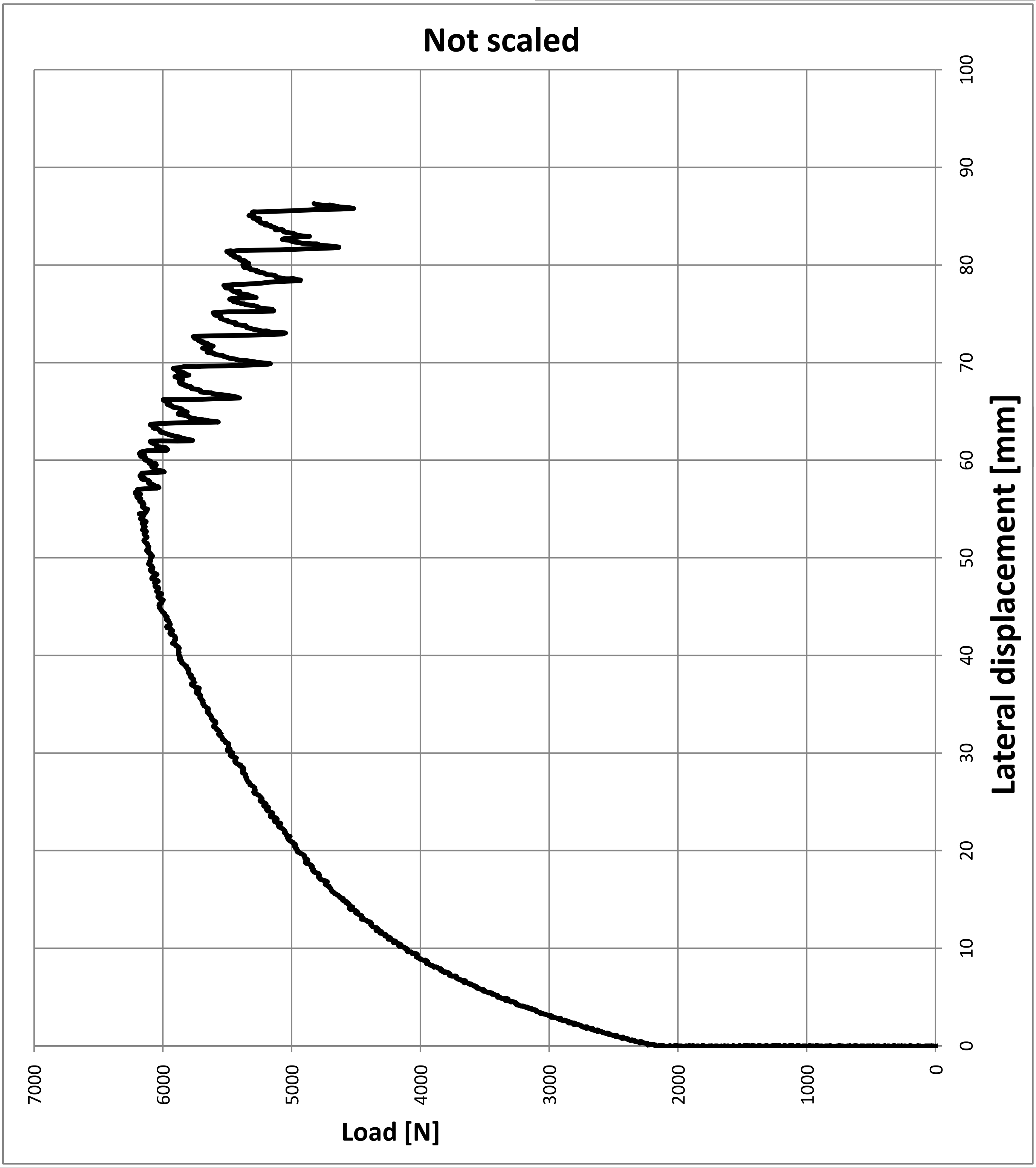
LATERAL LOAD TEST 15-05-2009

Test information		Preparation:	
Type	STATIC	Date:	14-05-2009
Pile diameter (D)	40 mm	Density,ρ	1660,9 kg/m^3
Embedment length (L)	6, D	Void ratio,e	0,593
Load height (e)	1 D	Rel. density, Id	0,855
Scale (N)	72,4		

Calibration date:

Novo100	16-12-2008
New LC	30-04-2009

Reprint of data from Klinkvort (2009b)



LATERAL LOAD TEST 25-05-2009	

Test information

Type	STATIC
Pile diameter (D)	40 mm
Embedment length (L)	8, D
Load height (e)	1 D
Scale (N)	71,59

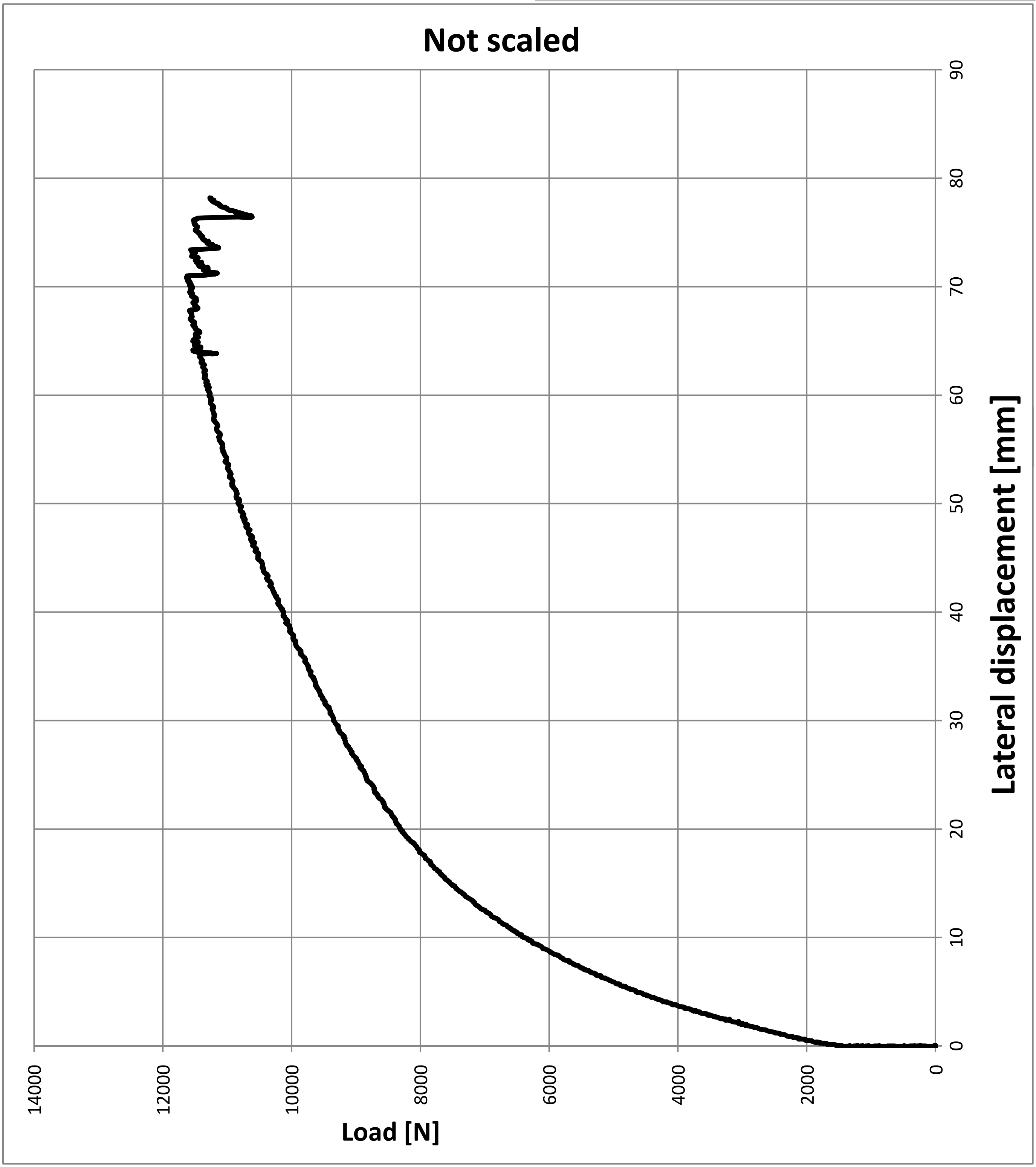
Calibration date:

Novo100	16-12-2008
LC7	30-04-2009

Preparation:

Date:	19-05-2009
Density,ρ	1666,1 kg/m^3
Void ratio,e	0,588
Rel. density, Id	0,871

Reprint of data from Klinkvort (2009b)



LATERAL LOAD TEST 23-10-2008

Test information

Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	6, D
Load height (e)	4,5 D
Scale (N)	64,65

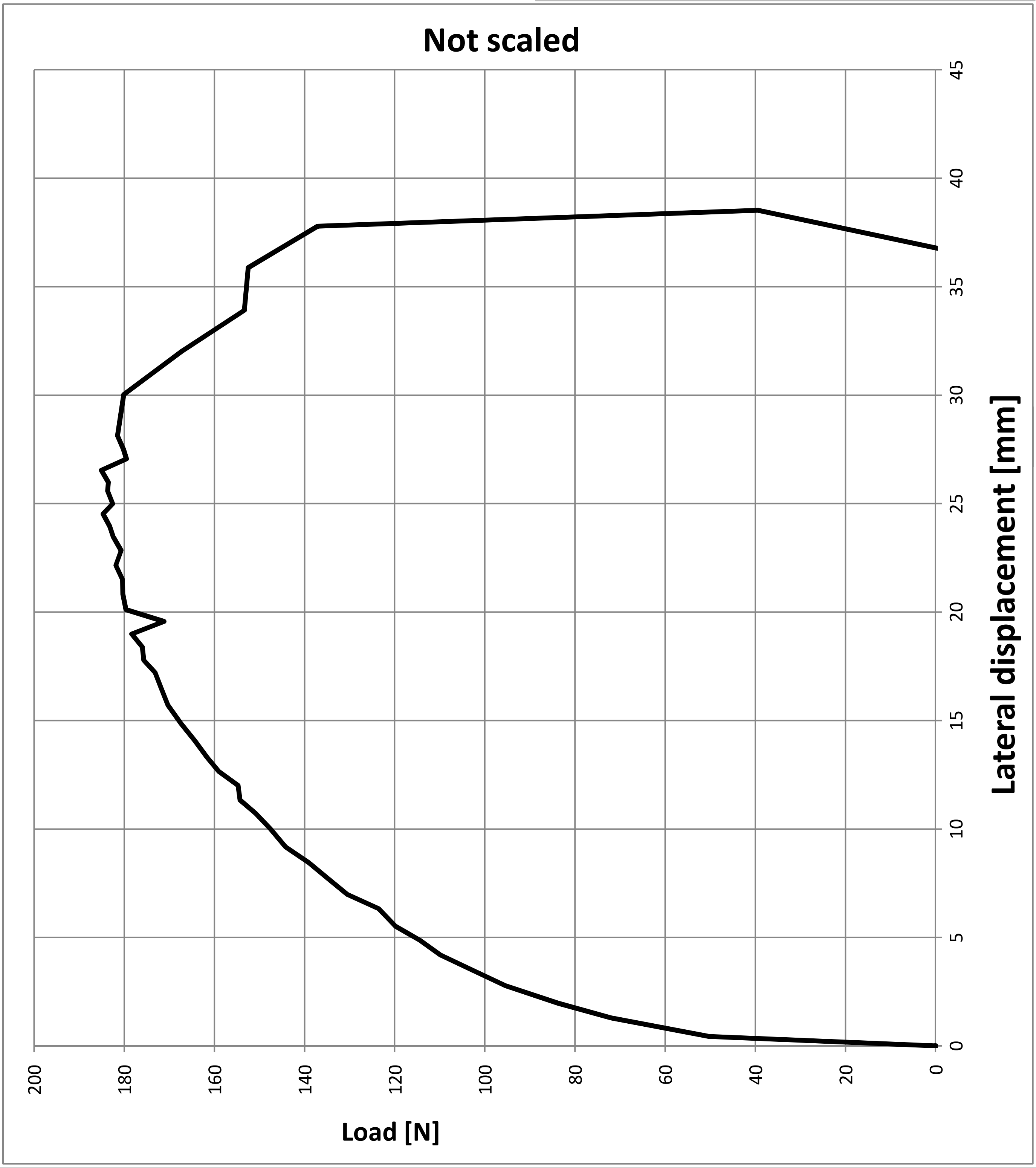
Calibration date:

Novo100	-
LC7	-

Preparation:

Date:	-
Density,ρ	1680 kg/m^3
Void ratio,e	0,575
Rel. density, Id	0,914

Preparation data (e & Id) is taken from Klinkvort (2009a) / Klinkvort et al (2010) and density is calculated



LATERAL LOAD TEST 24-10-2008

Test information

Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	8, D
Load height (e)	4,5 D
Scale (N)	63,78

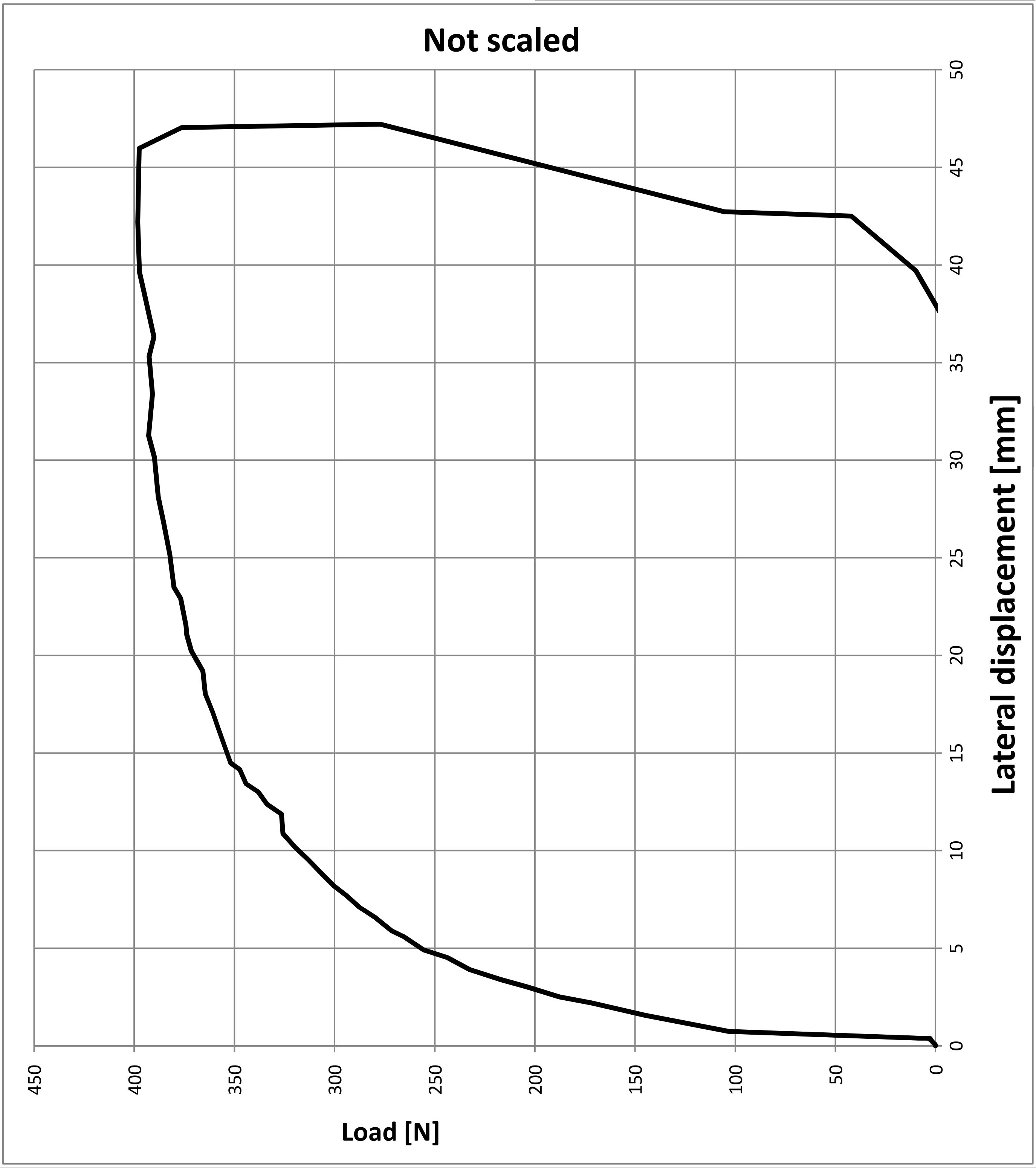
Calibration date:

Novo100	-
LC7	-

Preparation:

Date:	-
Density,ρ	1688,6 kg/m^3
Void ratio,e	0,567
Rel. density, Id	0,938

Preparation data (e & Id) is taken from Klinkvort (2009a) / Klinkvort et al (2010) and density is calculated



LATERAL LOAD TEST 18-08-2009	Page 1/1

Test information

Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	10, D
Load height (e)	4,5 D
Scale (N)	61,1

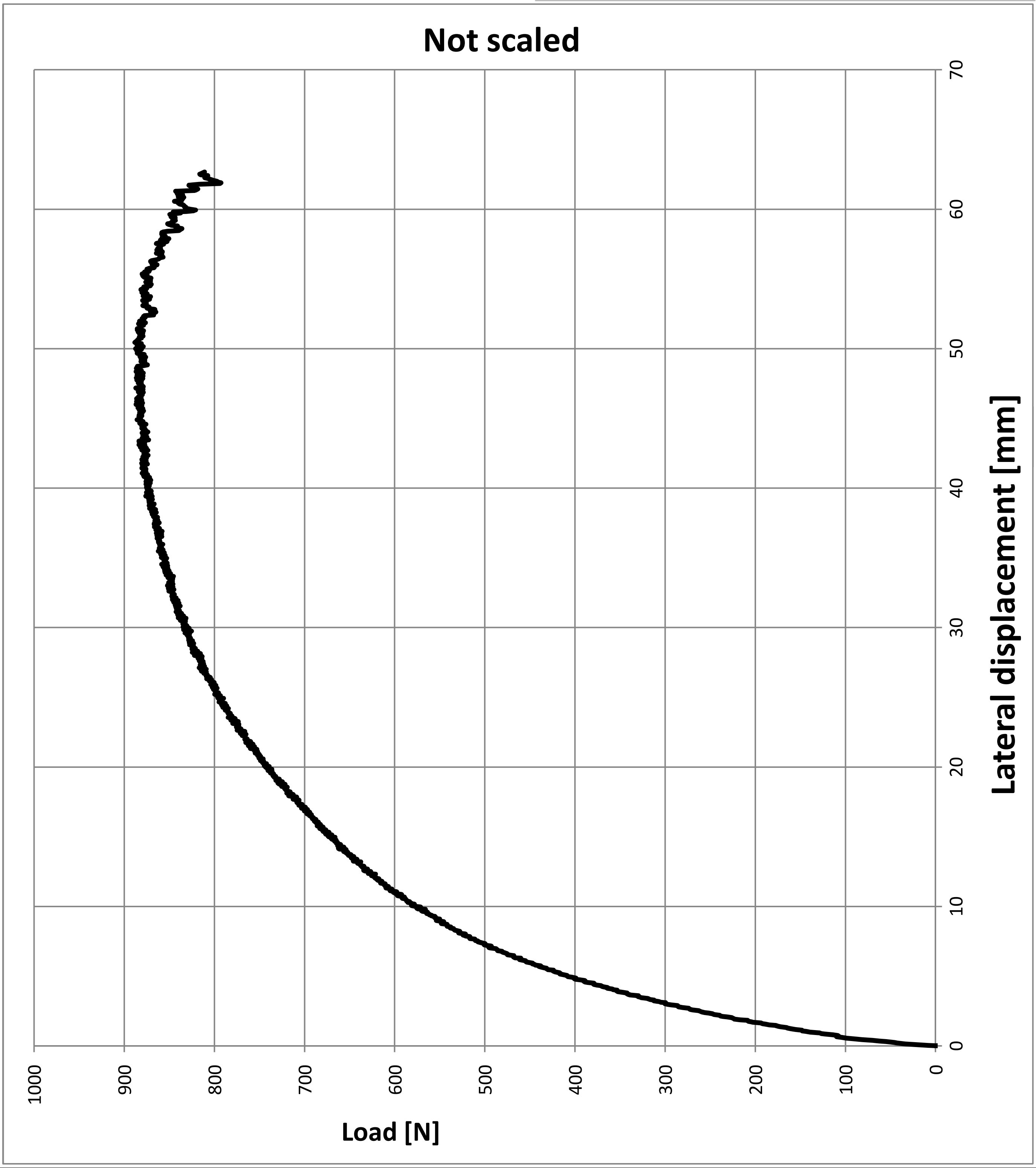
Calibration date:

Novo100	-
LC7	-

Preparation:

Date:	-
Density,ρ	1698,8 kg/m^3
Void ratio,e	0,558
Rel. density, Id	0,9694

Preparation data (e & Id) is taken from Klinkvort (2009a) / Klinkvort et al (2010) and density is calculated



LATERAL LOAD TEST 24-10-2008

Test information

Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	6, D
Load height (e)	6,5 D
Scale (N)	63,9

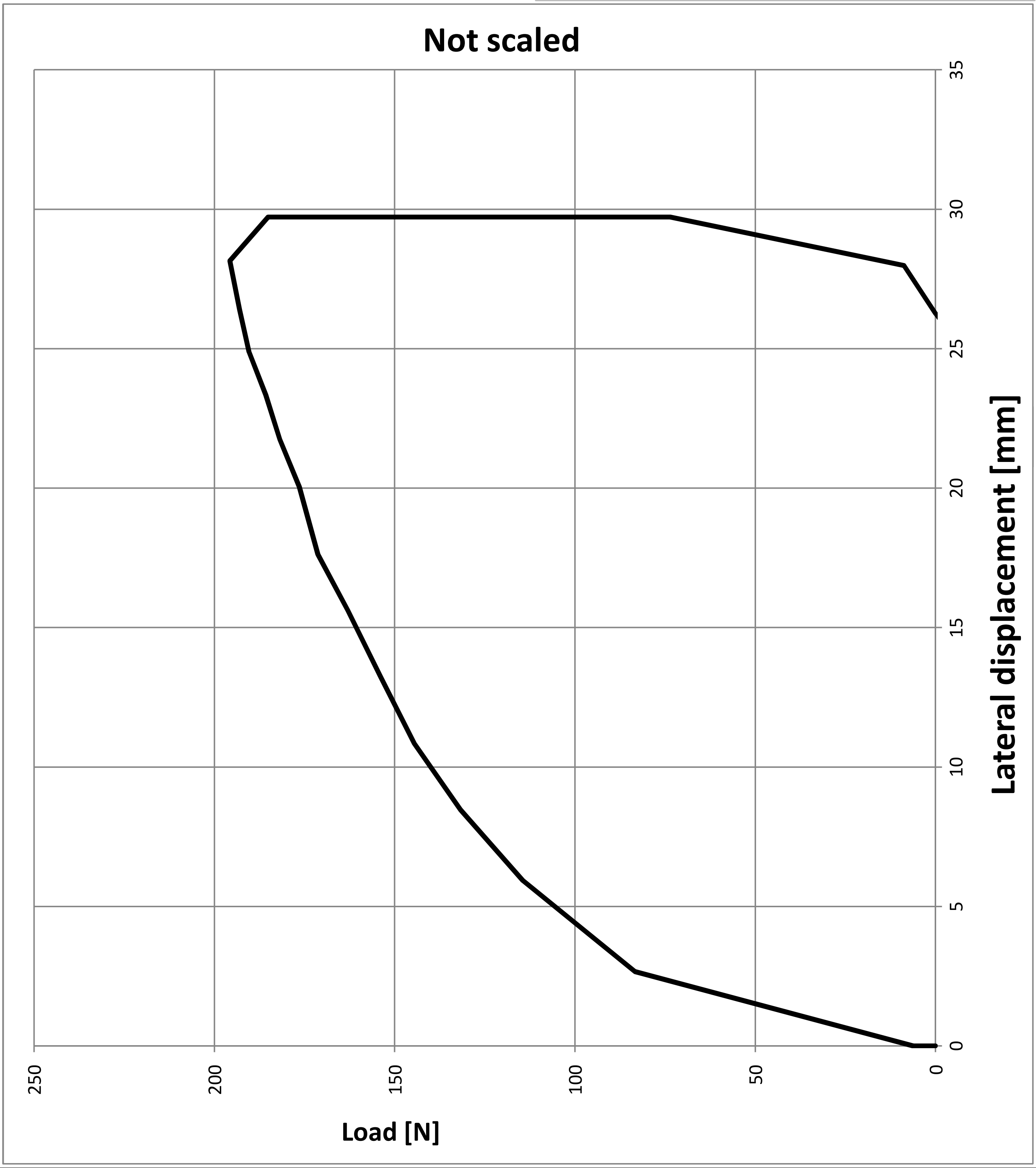
Calibration date:

Novo100	-
LC7	-

Preparation:

Date:	-
Density,ρ	1684,3 kg/m^3
Void ratio,e	0,571
Rel. density, Id	0,927

Preparation data (e & Id) is taken from Klinkvort (2009a) / Klinkvort et al (2010) and density is calculated



LATERAL LOAD TEST 26-08-2009	Page 1/1

Test information

Type	STATIC
Pile diameter (D)	16 mm
Embedment length (L)	8, D
Load height (e)	6,5 D
Scale (N)	60,6

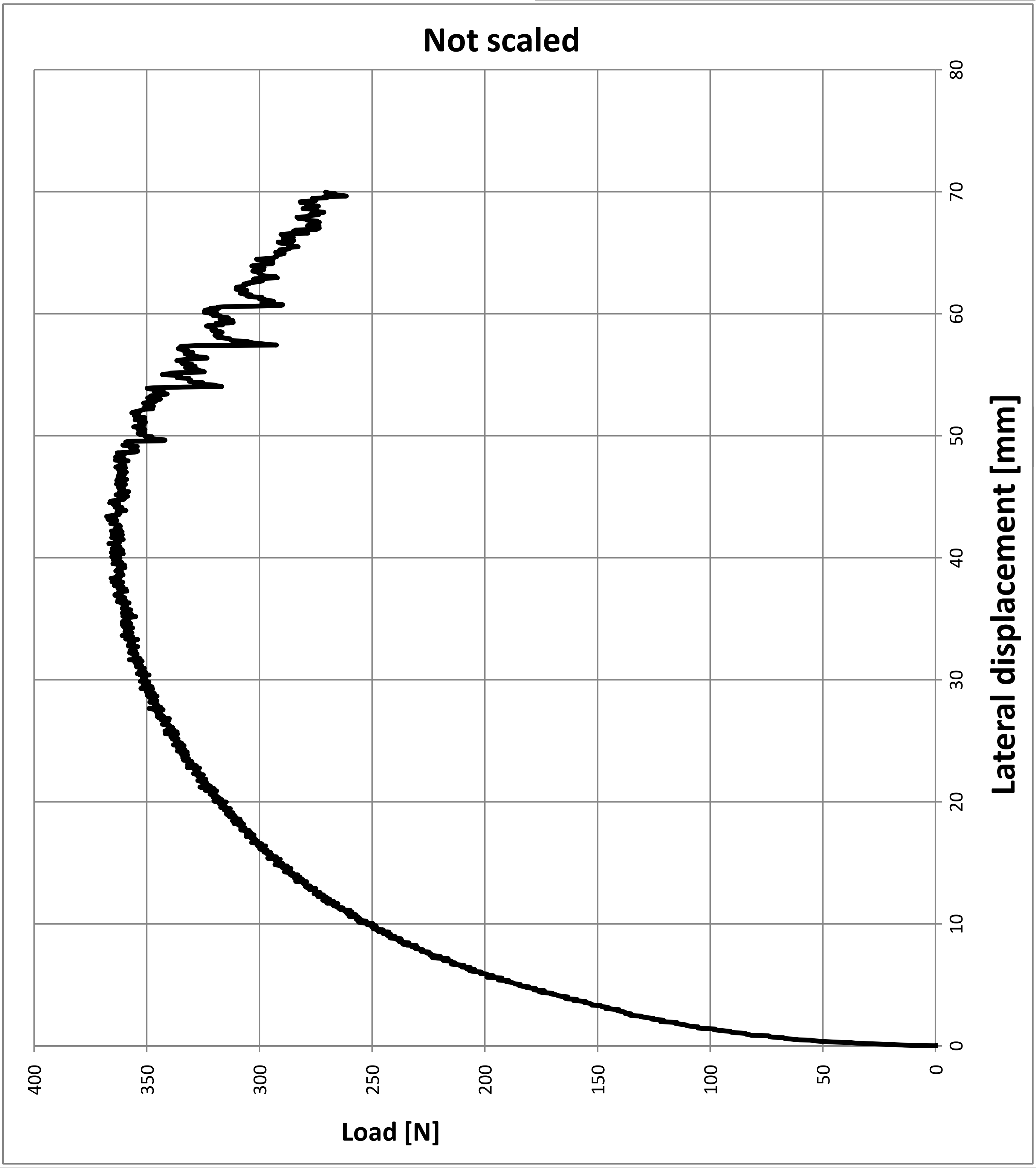
Calibration date:

Novo100	-
LC7	-

Preparation:

Date:	-
Density,ρ	1655,8 kg/m^3
Void ratio,e	0,598
Rel. density, Id	0,8391

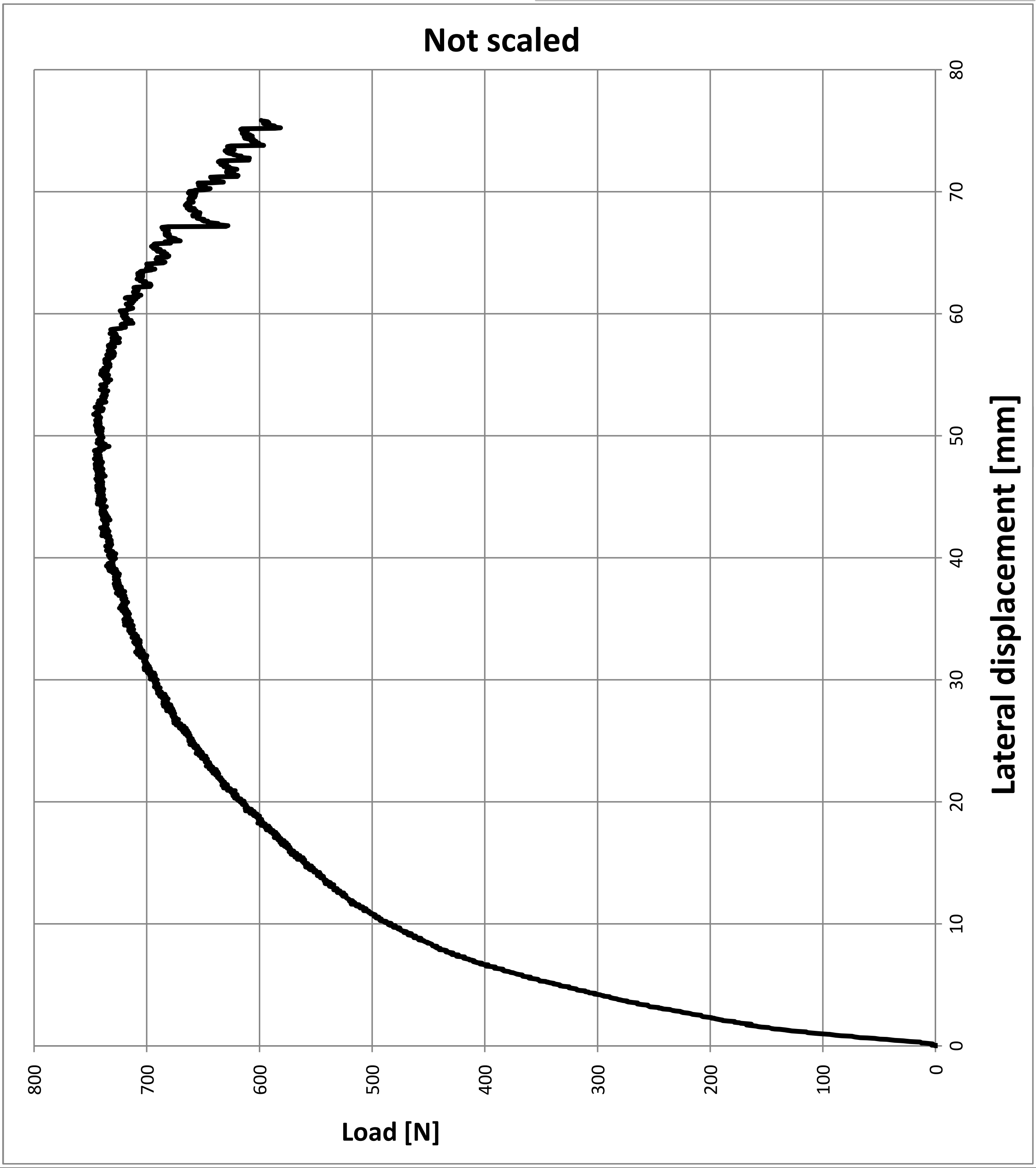
Preparation data (e & Id) is taken from Klinkvort (2009a) / Klinkvort et al (2010) and density is calculated



LATERAL LOAD TEST 17-08-2009	Page 1/1

Test information		Preparation:	
Type	STATIC	Date:	-
Pile diameter (D)	16 mm	Density,ρ	1685,5 kg/m^3
Embedment length (L)	10, D	Void ratio,e	0,570
Load height (e)	6,5 D	Rel. density, Id	0,9297
Scale (N)	61		
Calibration date:			
Novo100	-		
LC7	-		

Preparation data (e & Id) is taken from Klinkvort (2009a) / Klinkvort et al (2010) and density is calculated



LATERAL LOAD TEST 10-11-2008, TEST 1

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	6, D
Load height (e)	2,5 D
Scale (N)	60,6

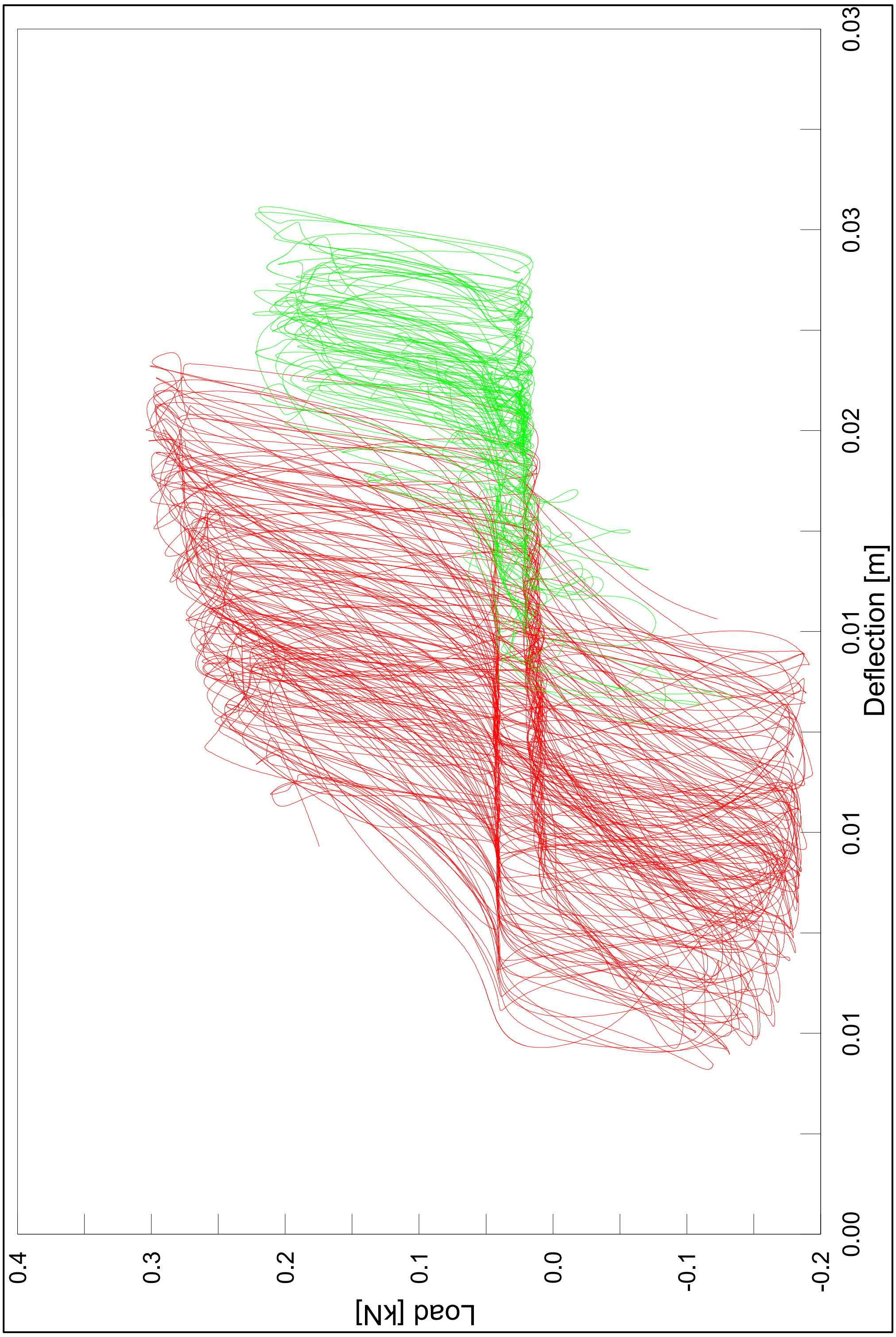
Calibration date:

Novo100	-
LC7	-

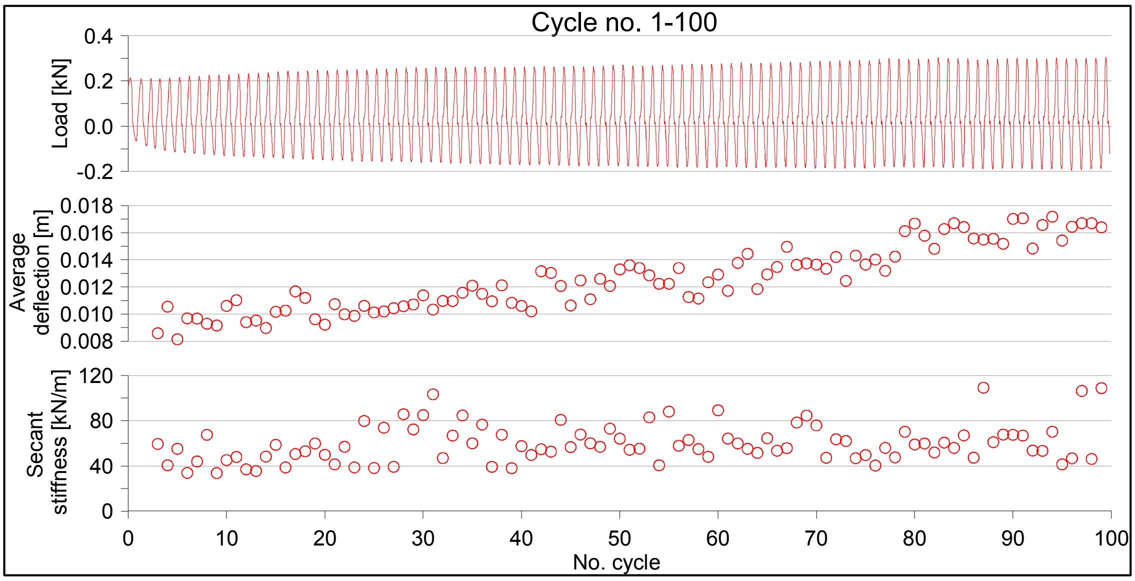
Preparation:

Date:	-
Density,ρ	1685,4 kg/m^3
Void ratio,e	0,570
Rel. density, Id	0,929

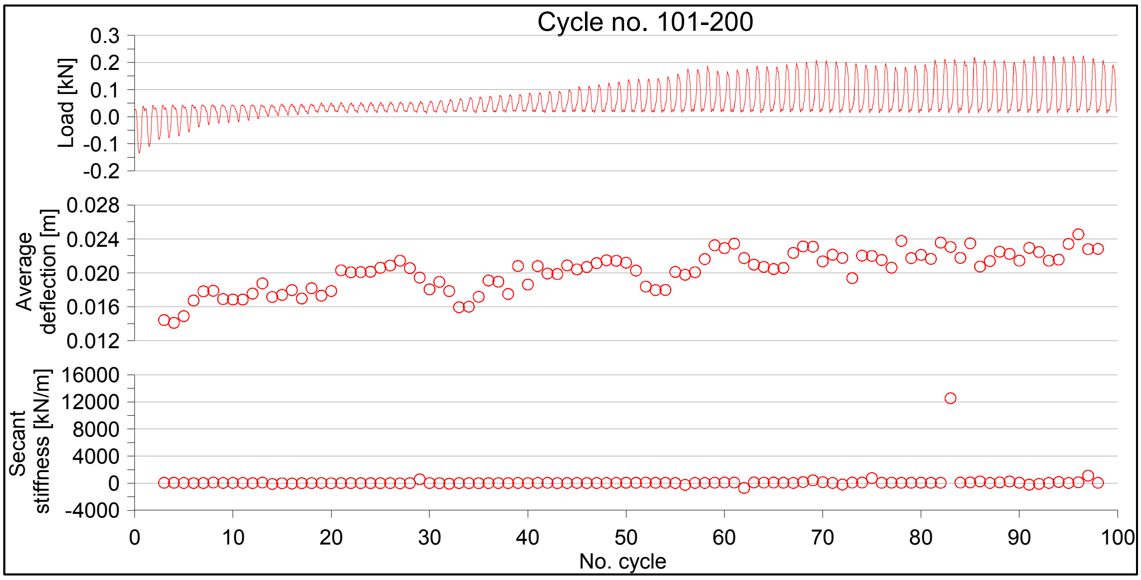
Preparation data (e & Id) is taken from Klinkvort (2009a) and density is calculated
Results are scaled to prototype scale



Large cycles, cycle 1-100



Small cycles, cycle 101-200



LATERAL LOAD TEST 10-11-2008, TEST 2	Page 1/2

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	8, D
Load height (e)	2,5 D
Scale (N)	60,3

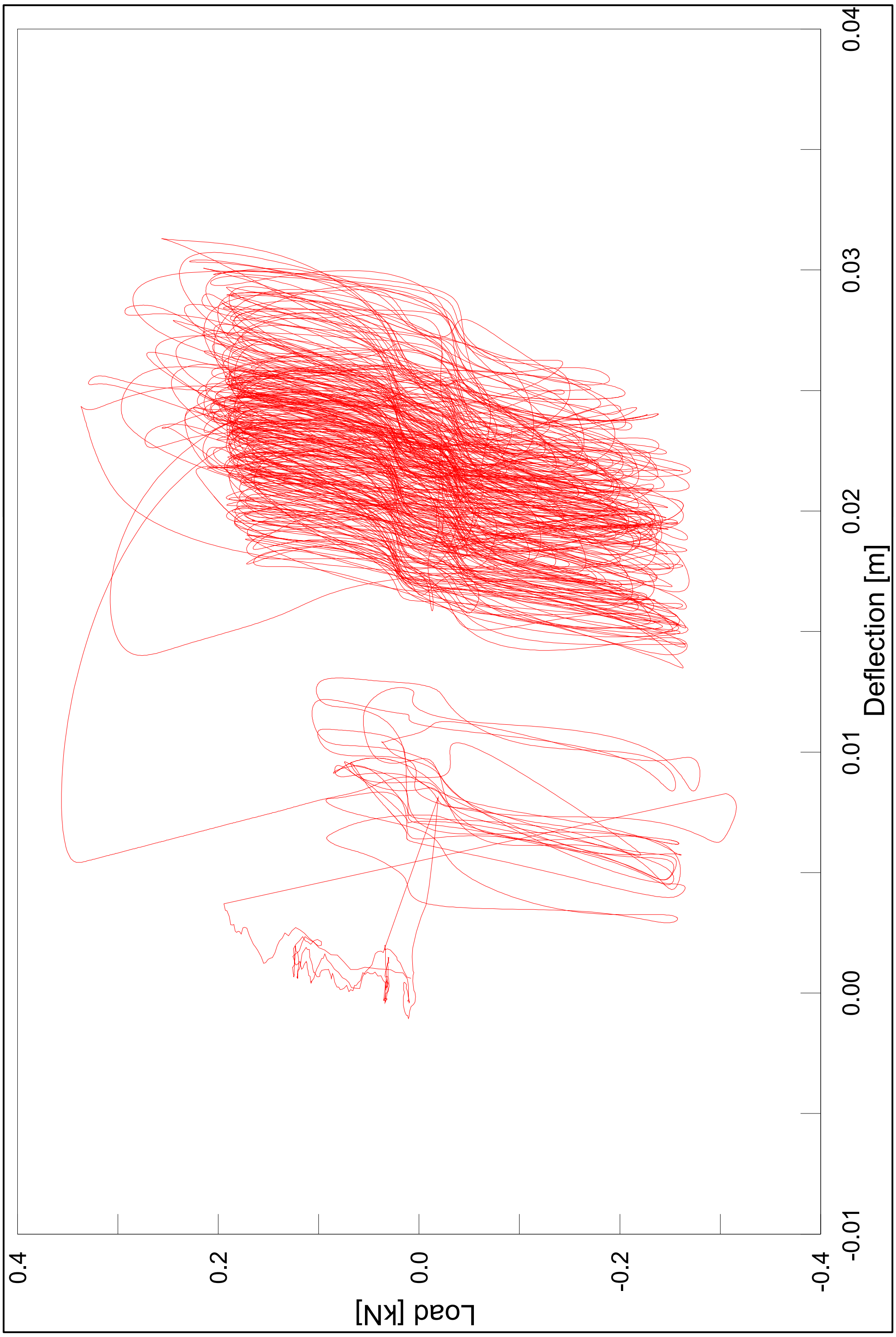
Calibration date:

Novo100	-
LC7	-

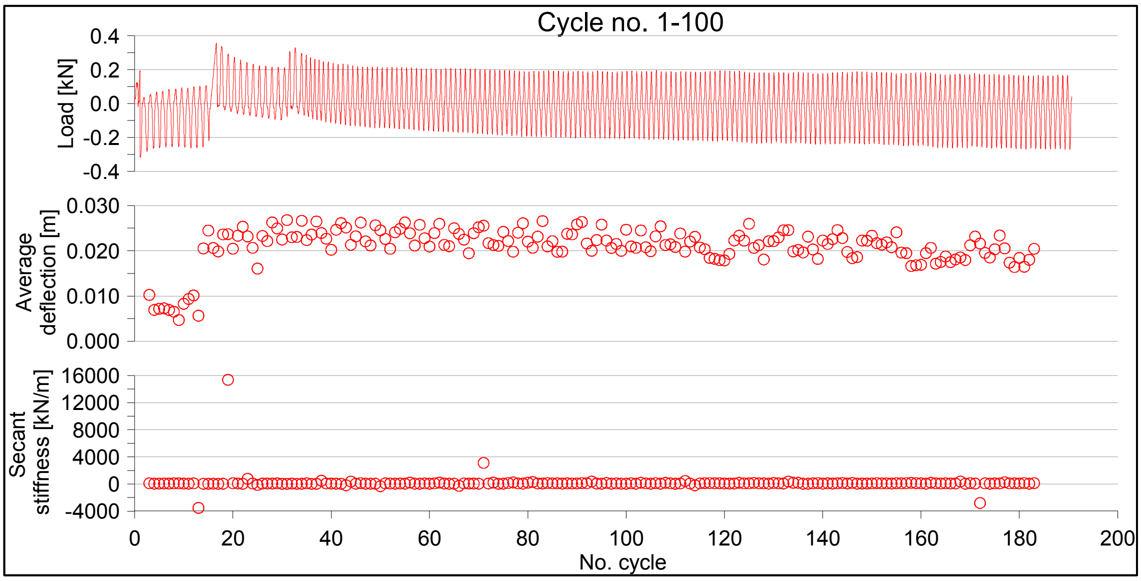
Preparation:

Date:	-
Density,ρ	1678,9 kg/m^3
Void ratio,e	0,576
Rel. density, Id	0,911

Preparation data (e & Id) is taken from Klinkvort (2009a) and density is calculated
Results are scaled to prototype scale



Large cycles, cycle 1-100



LATERAL LOAD TEST 08-11-2008

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	10, D
Load height (e)	2,5 D
Scale (N)	60,6

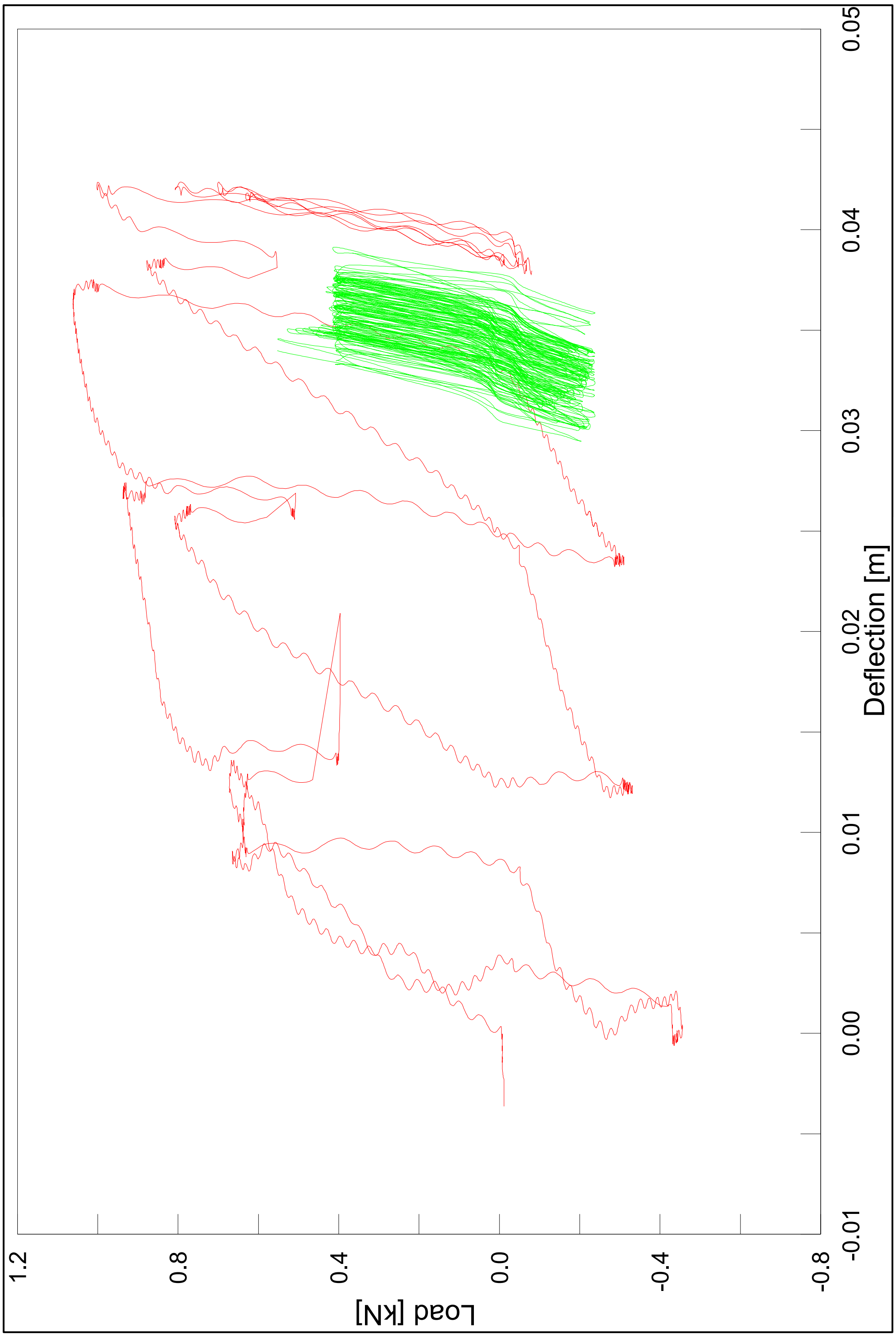
Calibration date:

Novo100	-
LC7	-

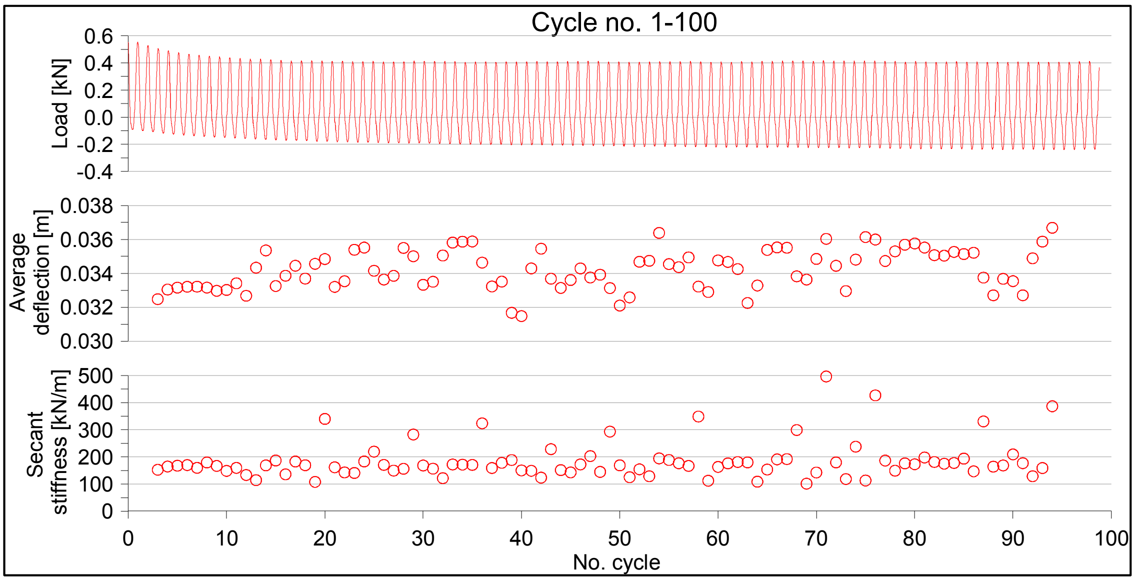
Preparation:

Date:	-
Density,ρ	1683,2 kg/m^3
Void ratio,e	0,572
Rel. density, Id	0,922

Preparation data (e & Id) is taken from Klinkvort (2009a) and density is calculated
Results are scaled to prototype scale



Large cycles, cycle 1-100



LATERAL LOAD TEST 17-11-2008

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	6, D
Load height (e)	4,5 D
Scale (N)	60,6

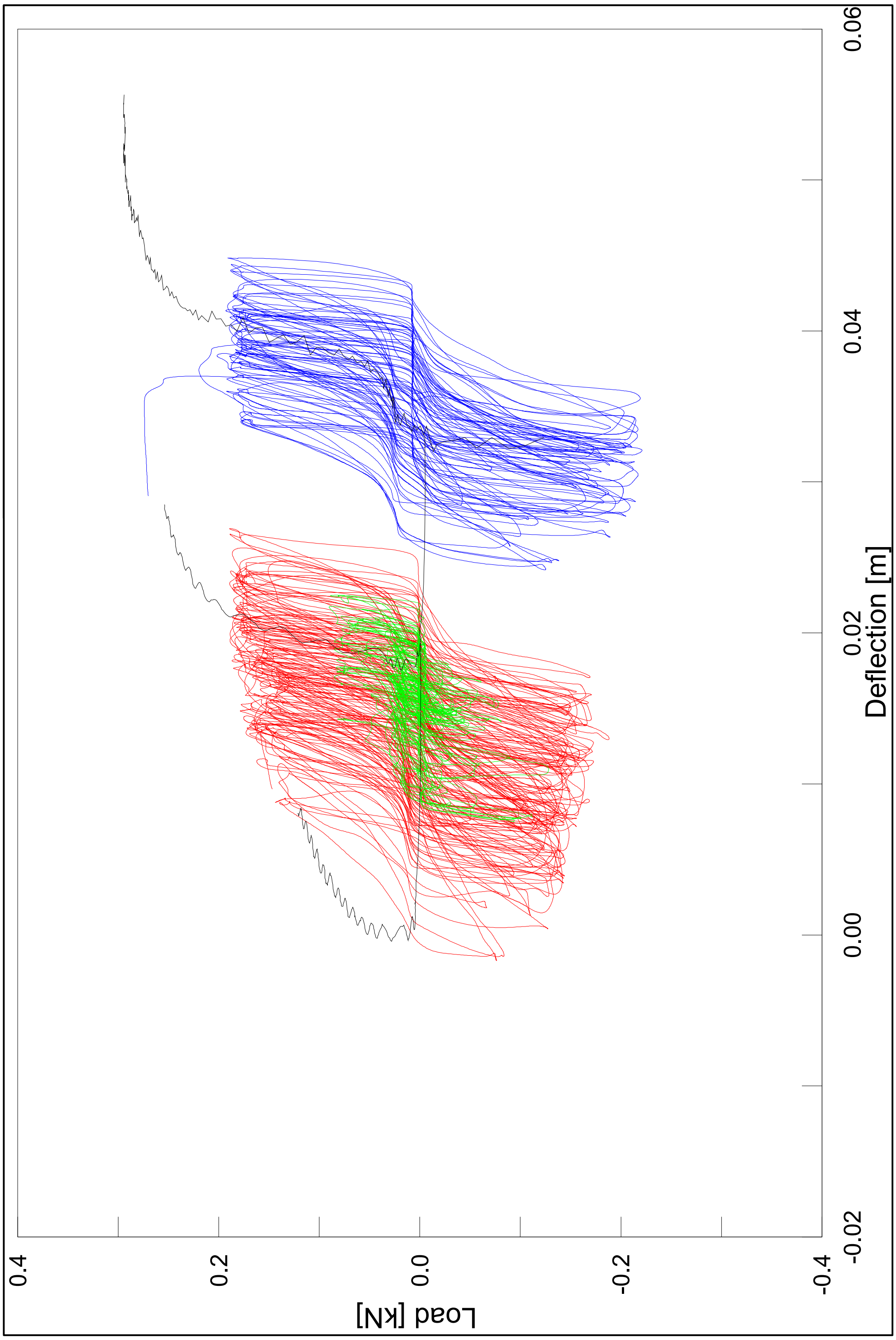
Calibration date:

Novo100	-
New LC	-

Preparation:

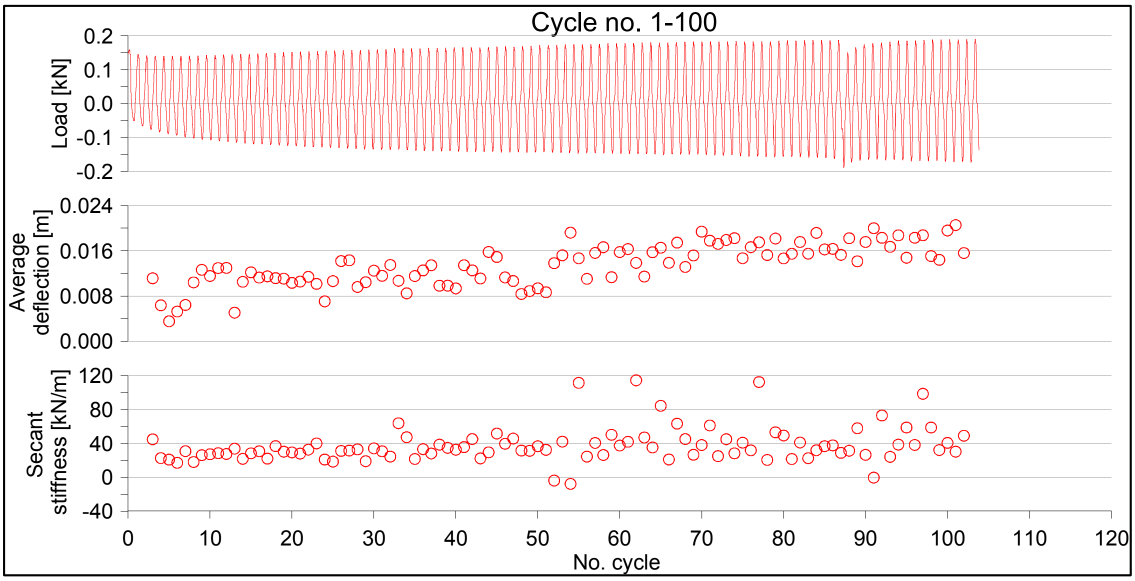
Date:	-
Density,ρ	1681,1 kg/m^3
Void ratio,e	0,574
Rel. density, Id	0,915

Preparation data (e & Id) is taken from Klinkvort (2009a) and density is calculated
Results are scaled to prototype scale

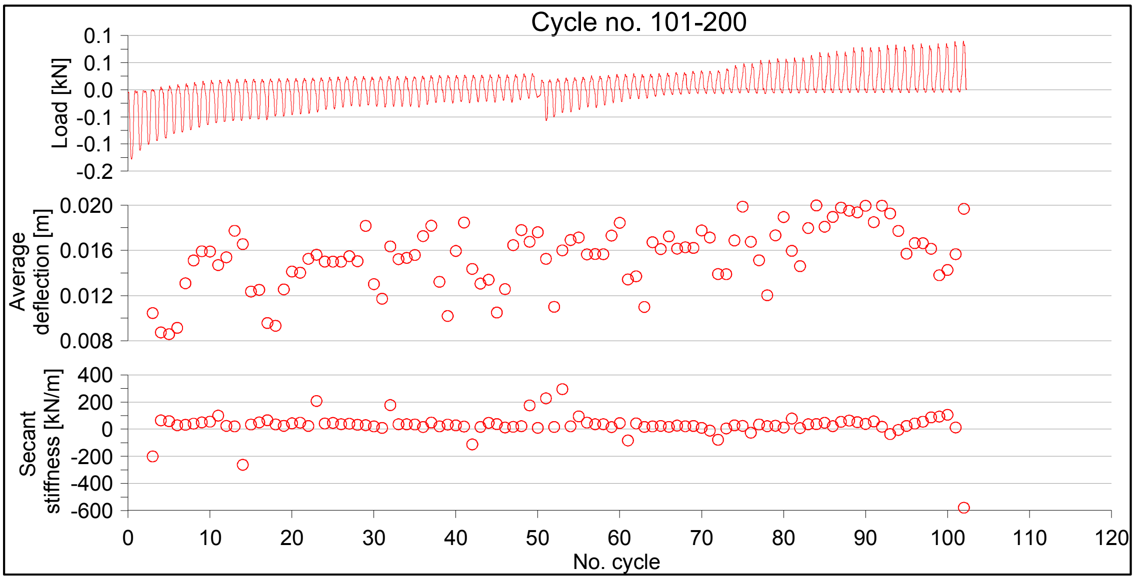


LATERAL LOAD TEST 17-11-2008

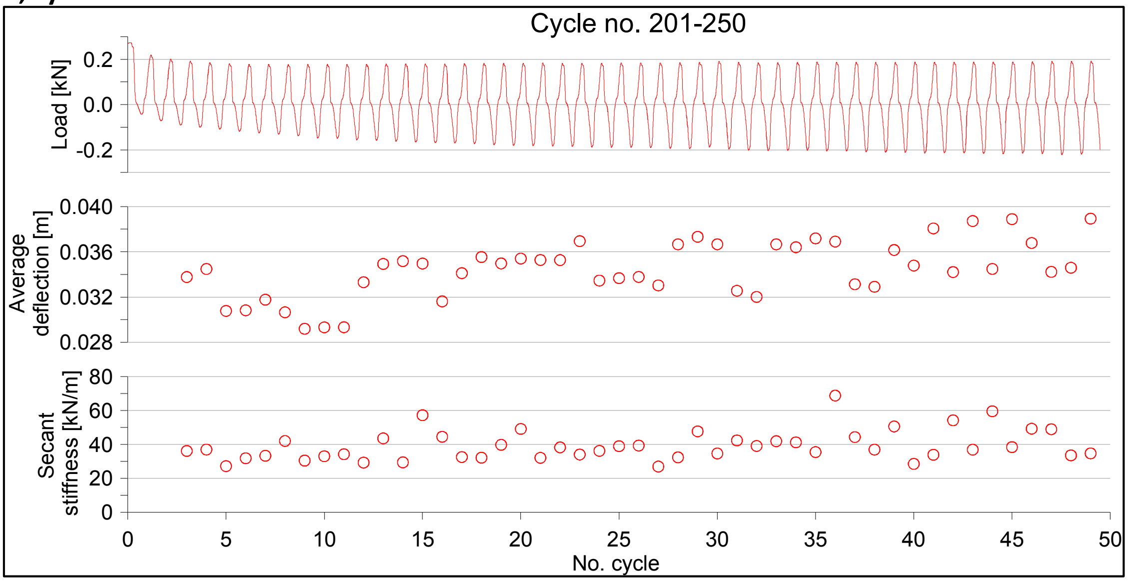
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-250



LATERAL LOAD TEST 12-11-2008

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	8, D
Load height (e)	4,5 D
Scale (N)	60,4

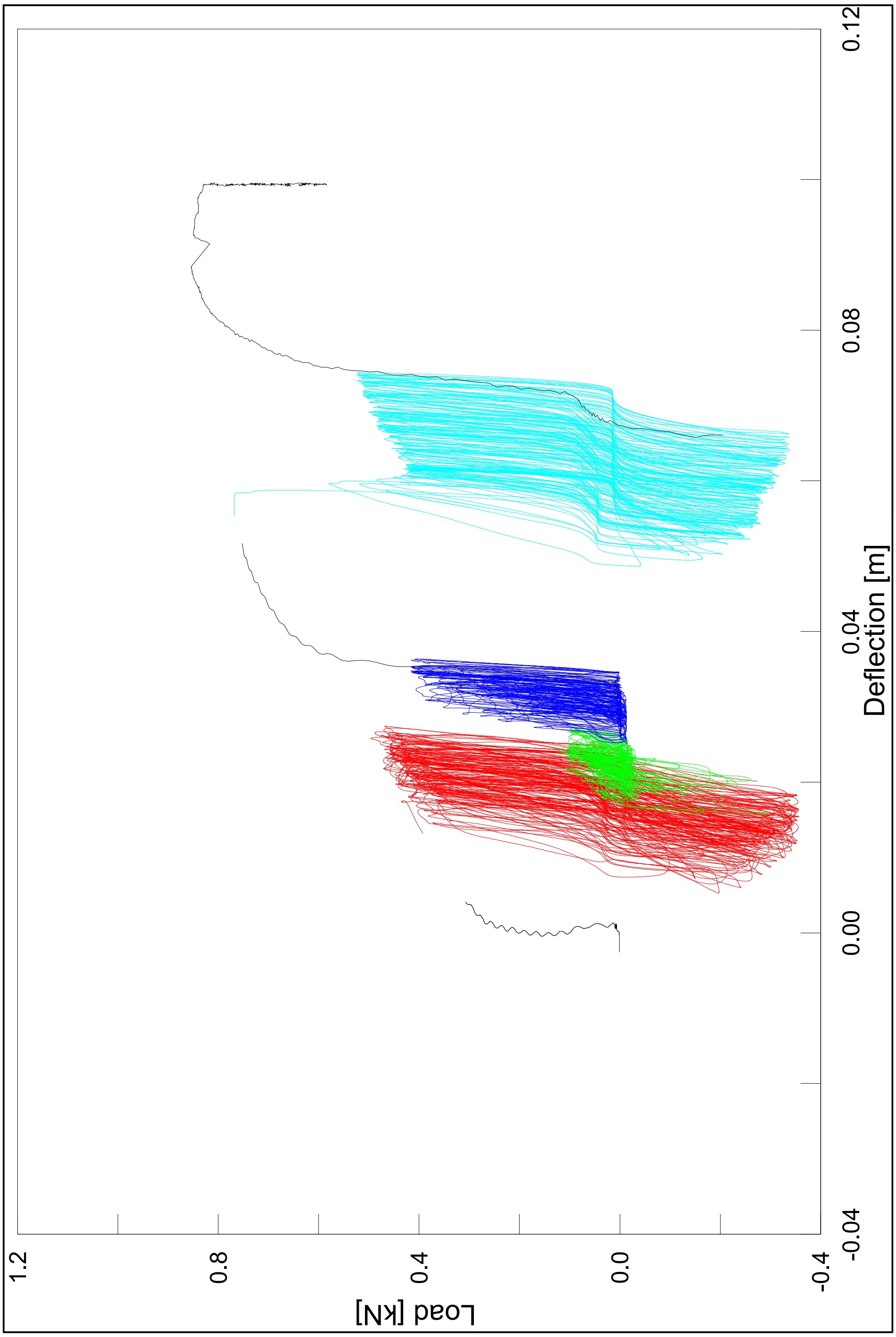
Calibration date:

Novo100	-
LC7	-

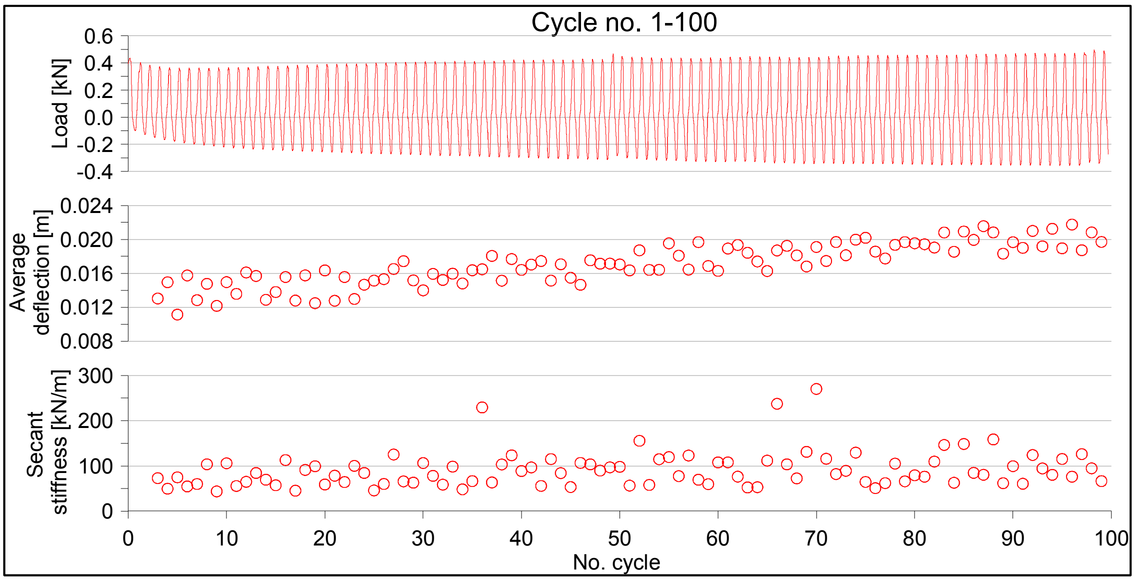
Preparation:

Date:	-
Density,ρ	1689,7 kg/m^3
Void ratio,e	0,566
Rel. density, Id	0,942

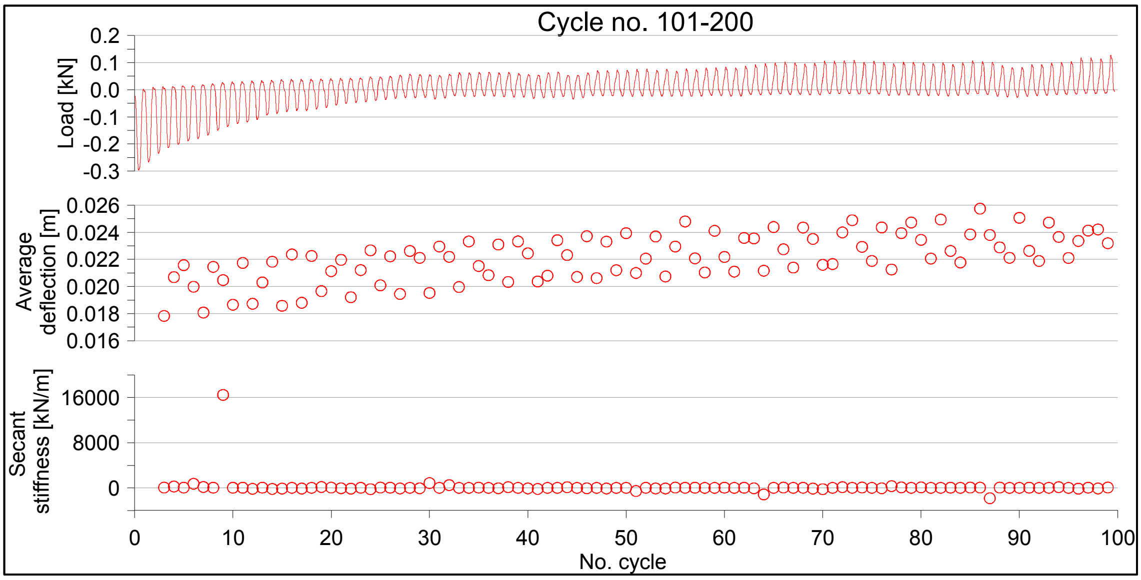
Preparation data (e & Id) is taken from Klinkvort (2009a) and density is calculated
Results are scaled to prototype scale



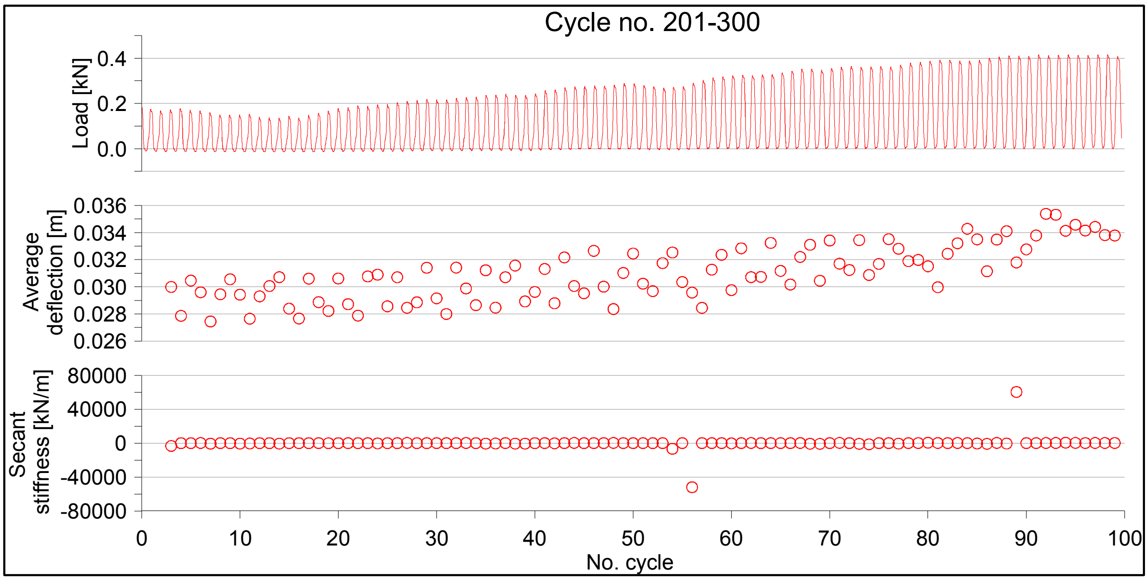
Large cycles, cycle 1-100



Small cycles, cycle 101-200

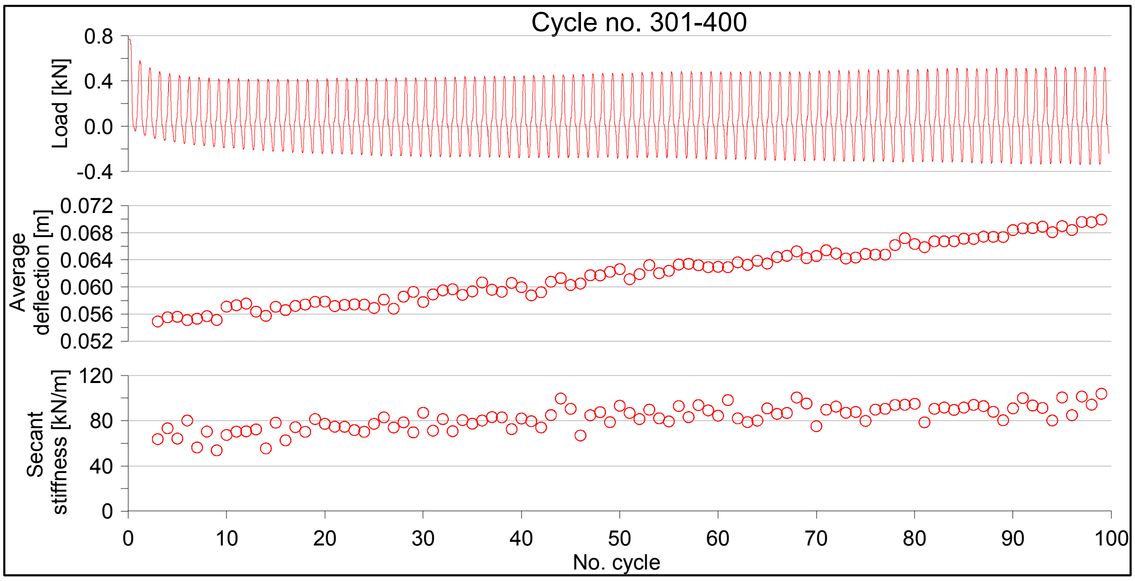


Medium cycles, cycle 201-300



LATERAL LOAD TEST 12-11-2008

Large cycles, cycle 301-400



LATERAL LOAD TEST 20-11-2008

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	6, D
Load height (e)	6,5 D
Scale (N)	60,6

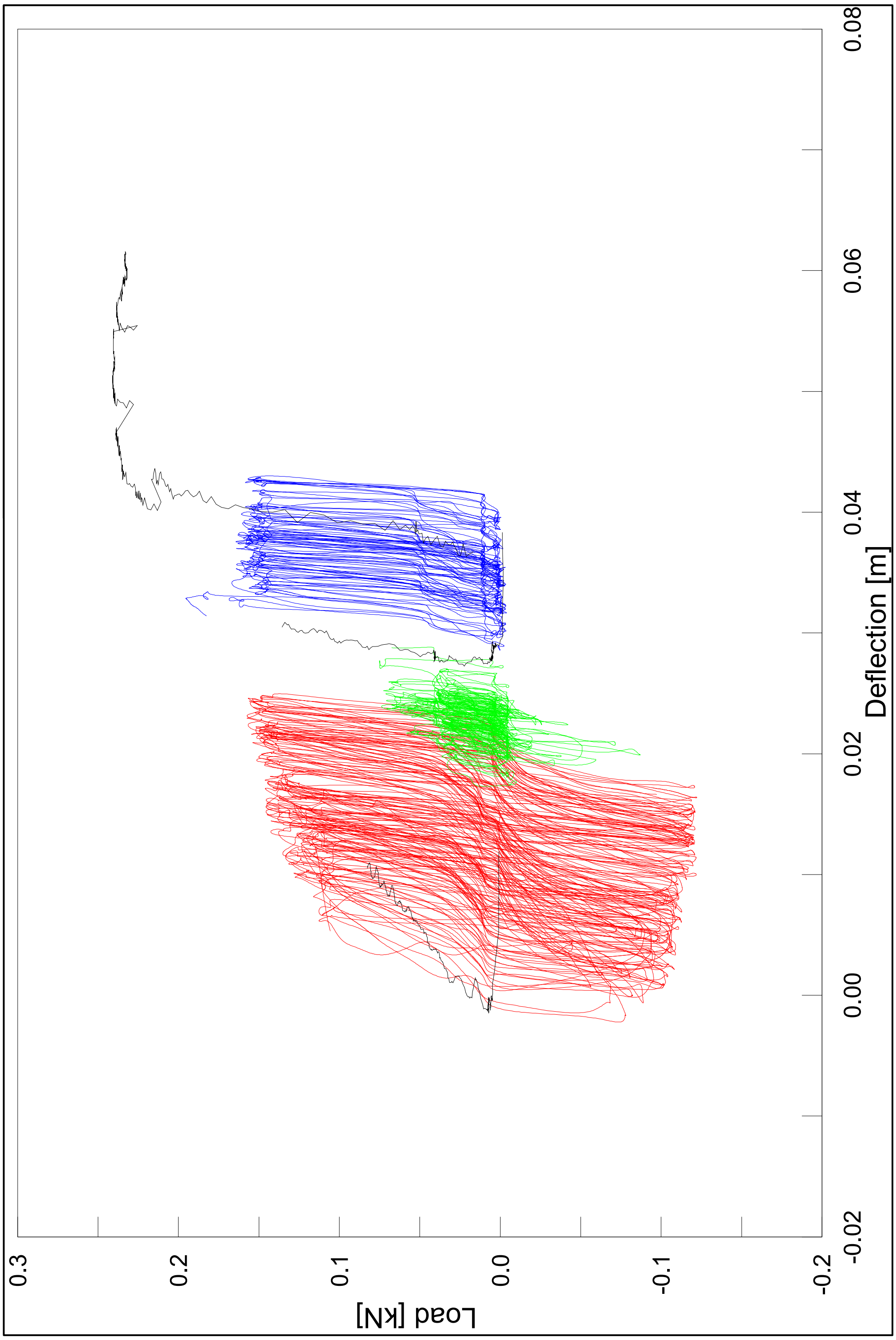
Calibration date:

Novo100	-
New LC	-

Preparation:

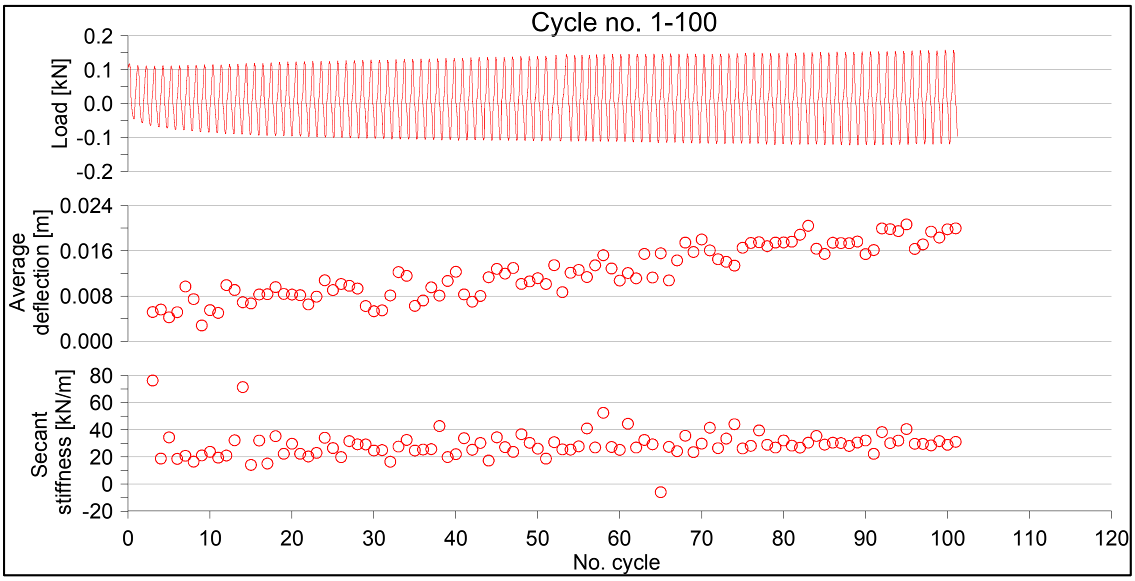
Date:	-
Density,ρ	1694 kg/m^3
Void ratio,e	0,562
Rel. density, Id	0,955

Preparation data (e & Id) is taken from Klinkvort (2009a) and density is calculated
Results are scaled to prototype scale

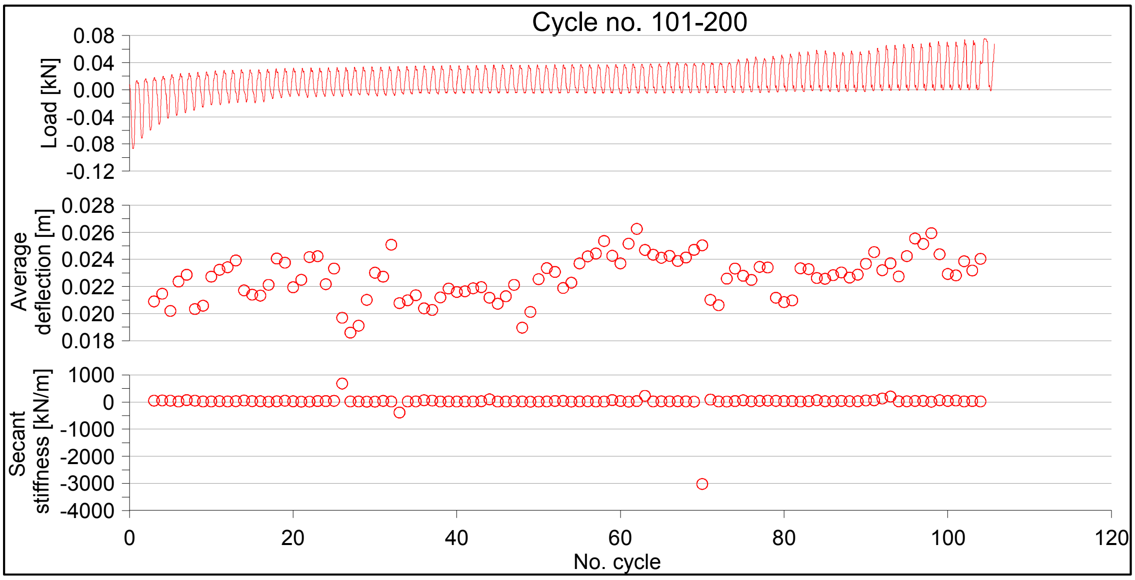


LATERAL LOAD TEST 20-11-2008

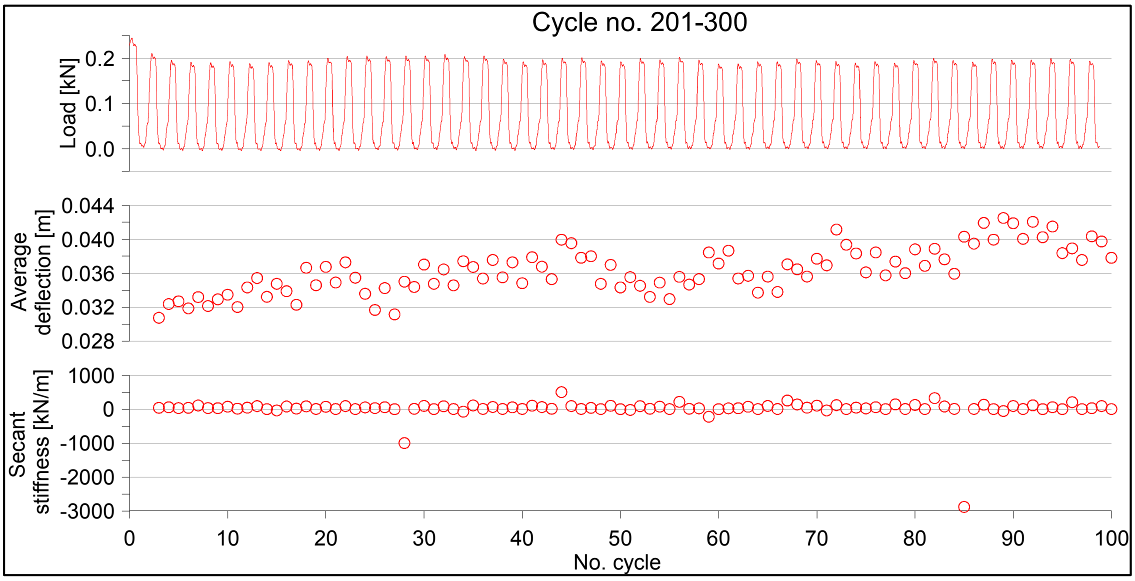
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 22-04-2009

Test information

Type	CYCLIC
Pile diameter (D)	28 mm
Embedment length (L)	6, D
Load height (e)	1,429 D
Scale (N)	69,4

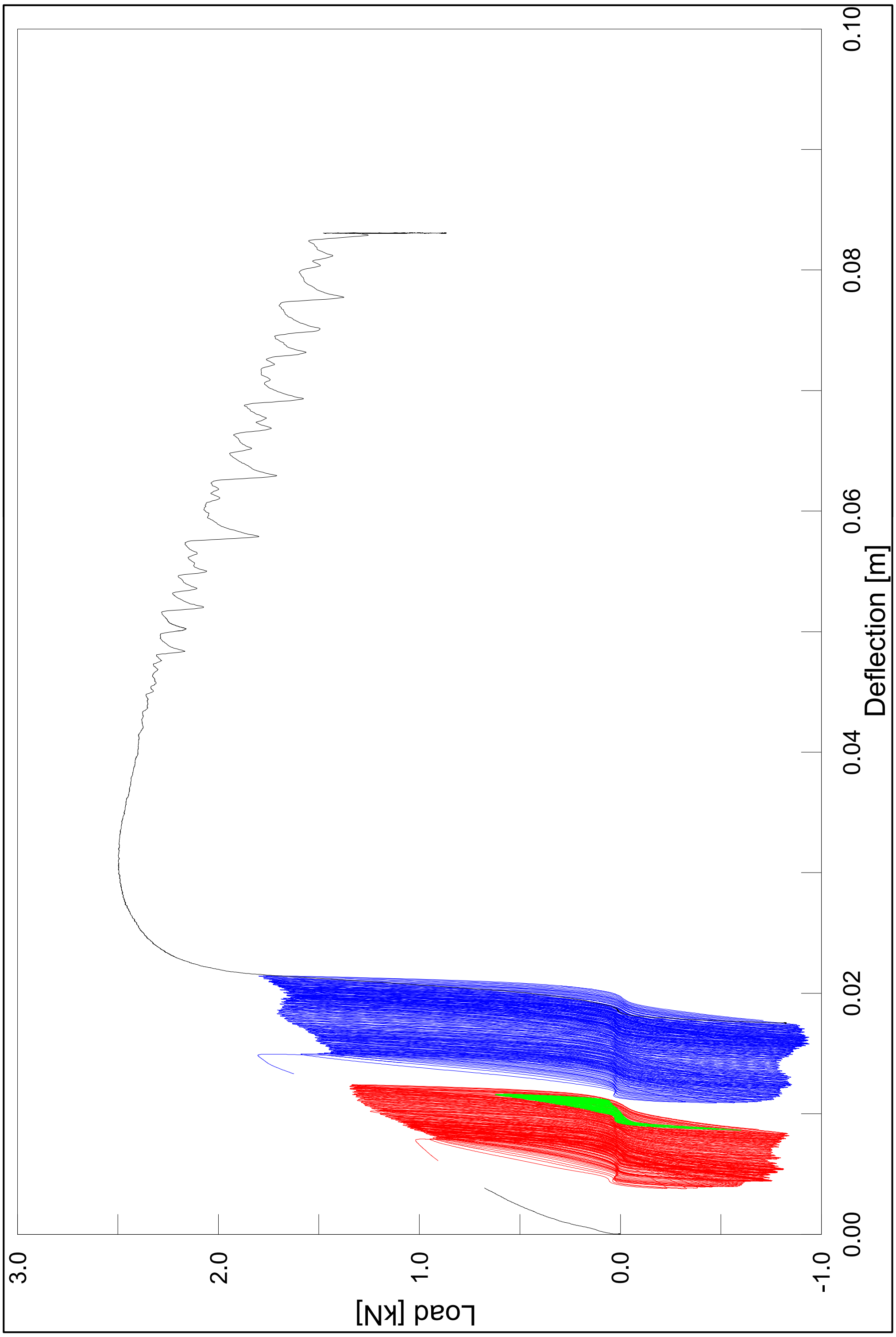
Calibration date:

Novo100	28-02-2008
New LC	30-04-2009

Preparation:

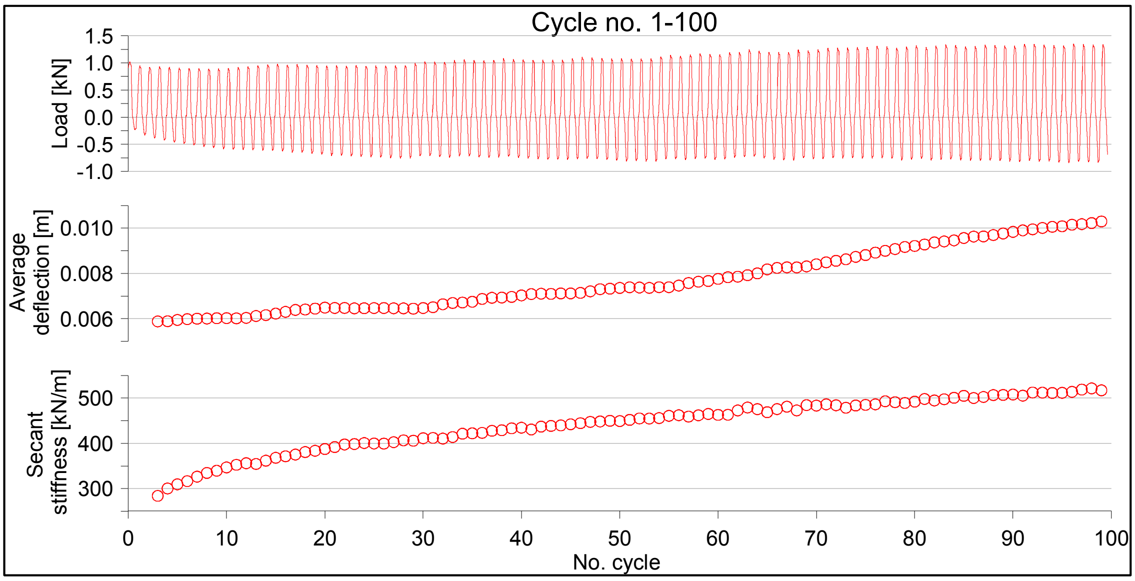
Date:	21-04-2009
Density,ρ	1652,2 kg/m^3
Void ratio,e	0,601
Rel. density, Id	0,828

Results are scaled to prototype scale

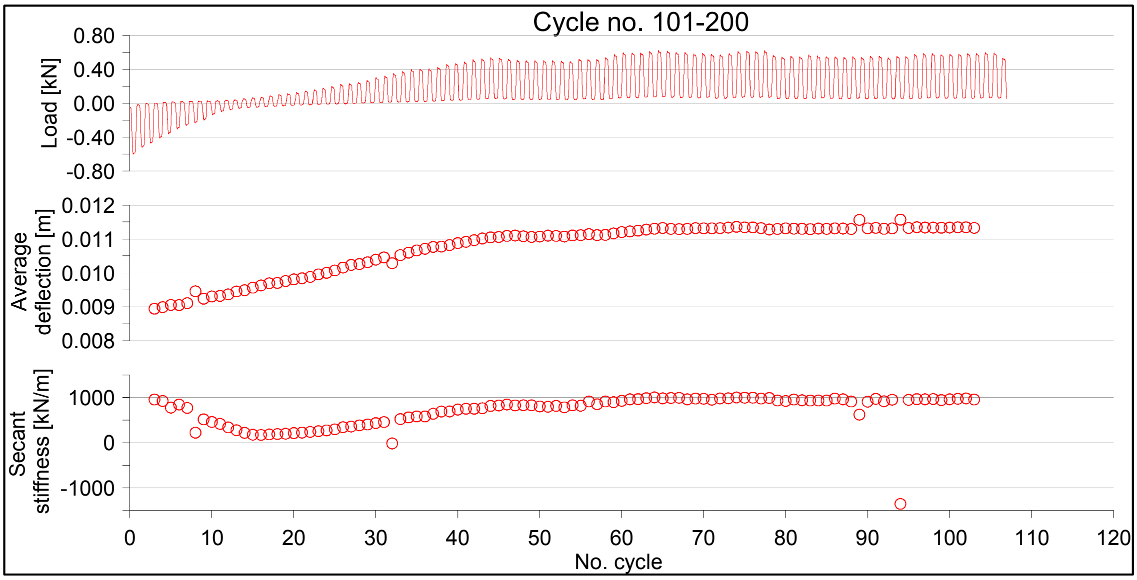


LATERAL LOAD TEST 22-04-2009

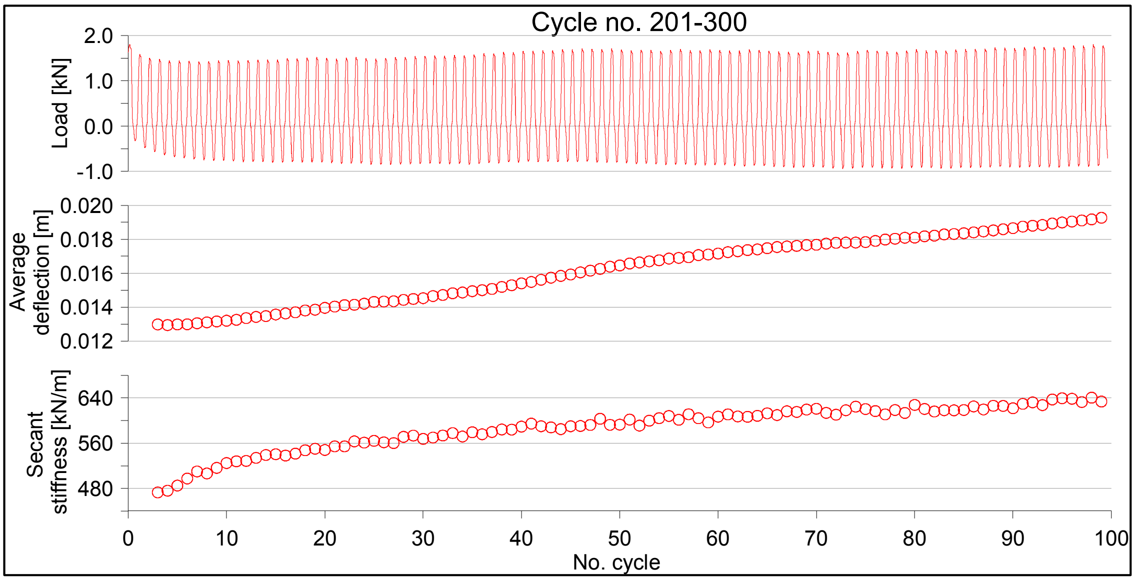
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 23-04-2009, TEST 1

Test information

Type	CYCLIC
Pile diameter (D)	28 mm
Embedment length (L)	8, D
Load height (e)	1,429 D
Scale (N)	68,9

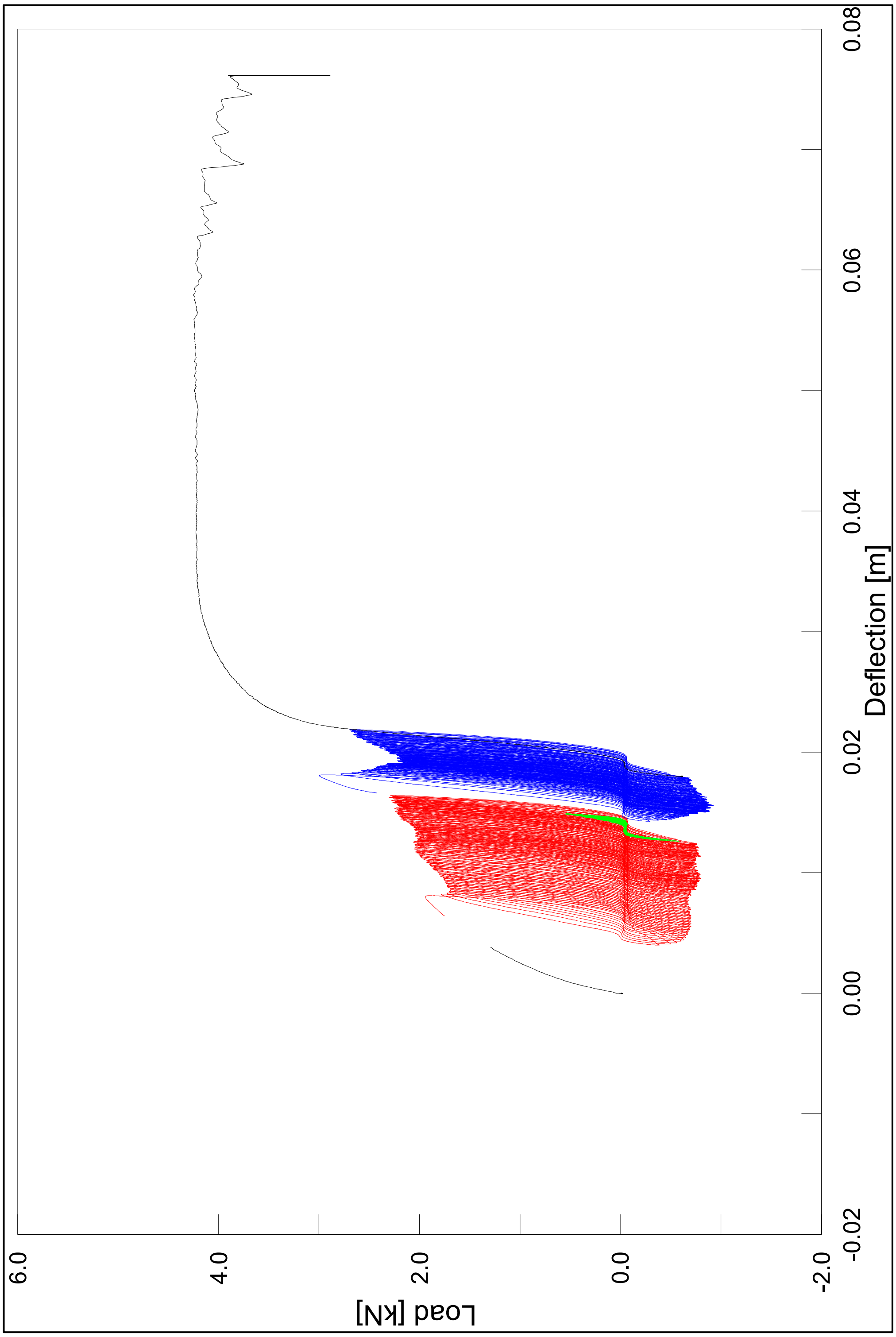
Calibration date:

Novo100	28-02-2008
New LC	30-04-2009

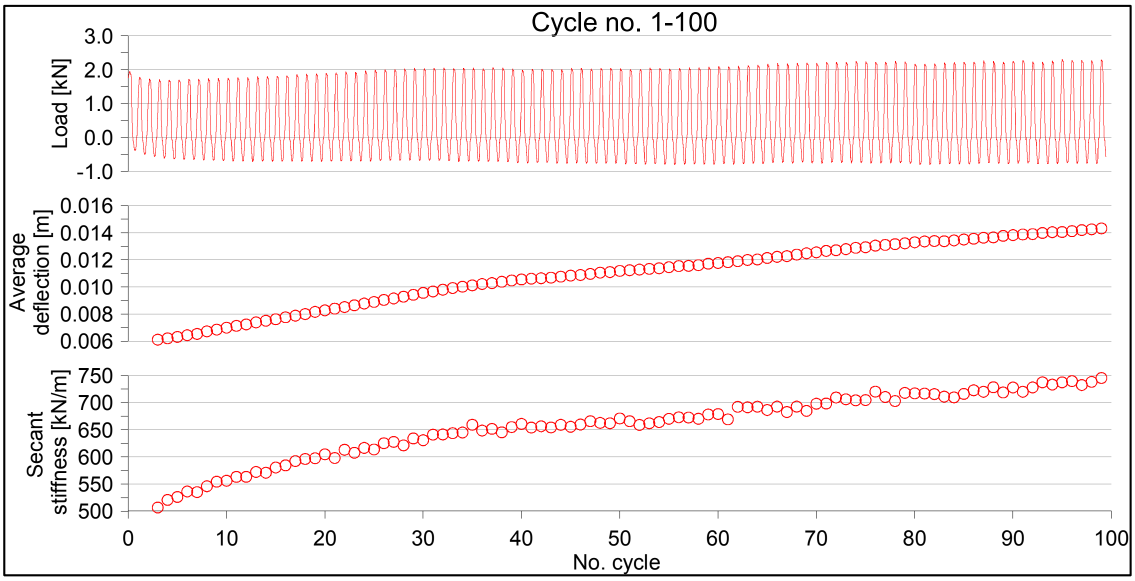
Preparation:

Date:	22-04-2009
Density,ρ	1647,8 kg/m^3
Void ratio,e	0,606
Rel. density, Id	0,814

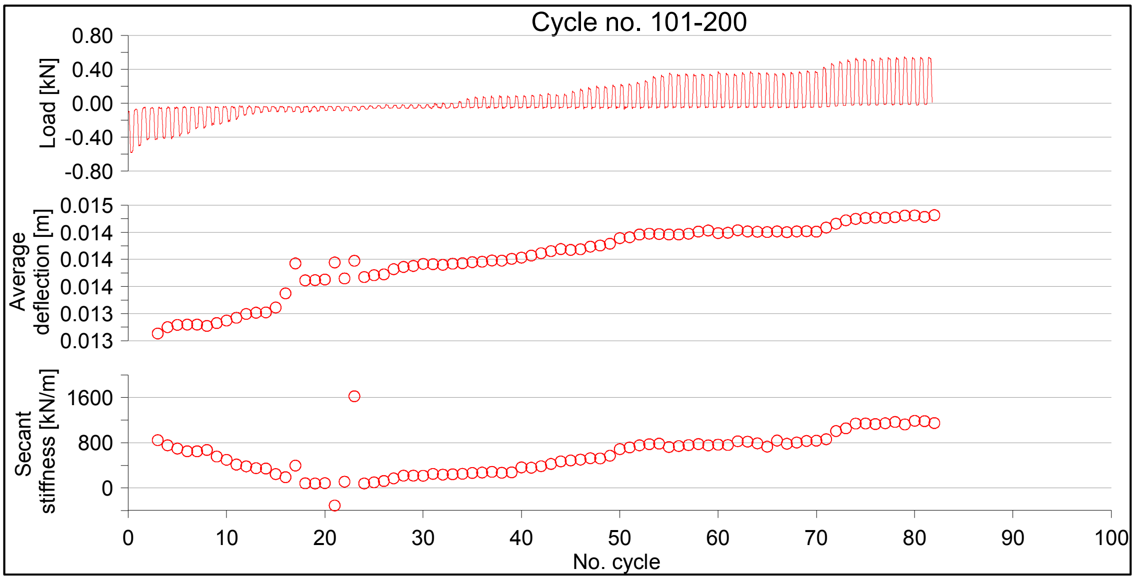
Results are scaled to prototype scale



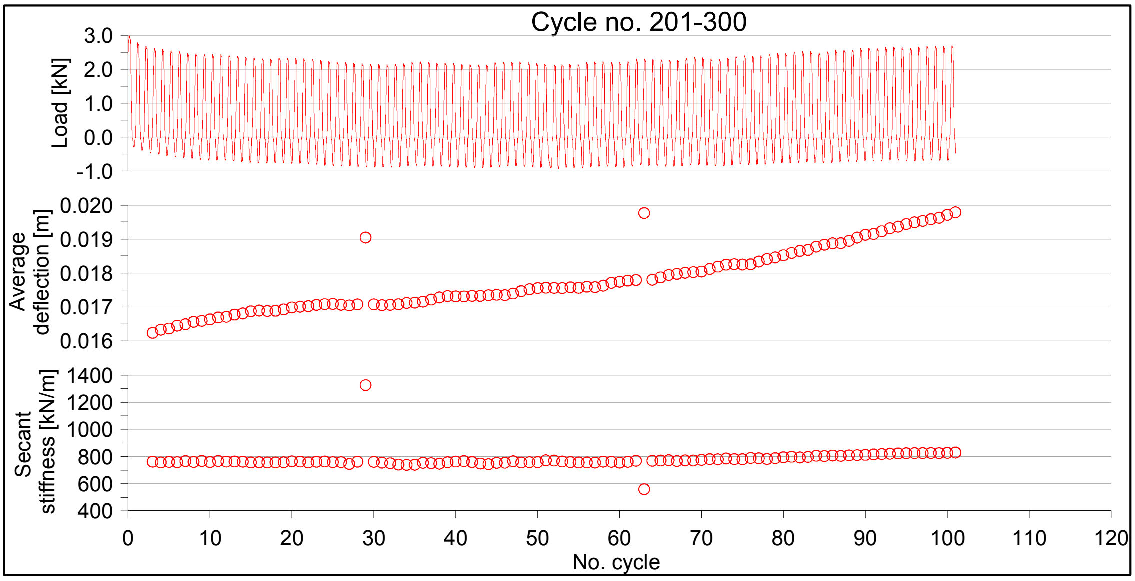
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



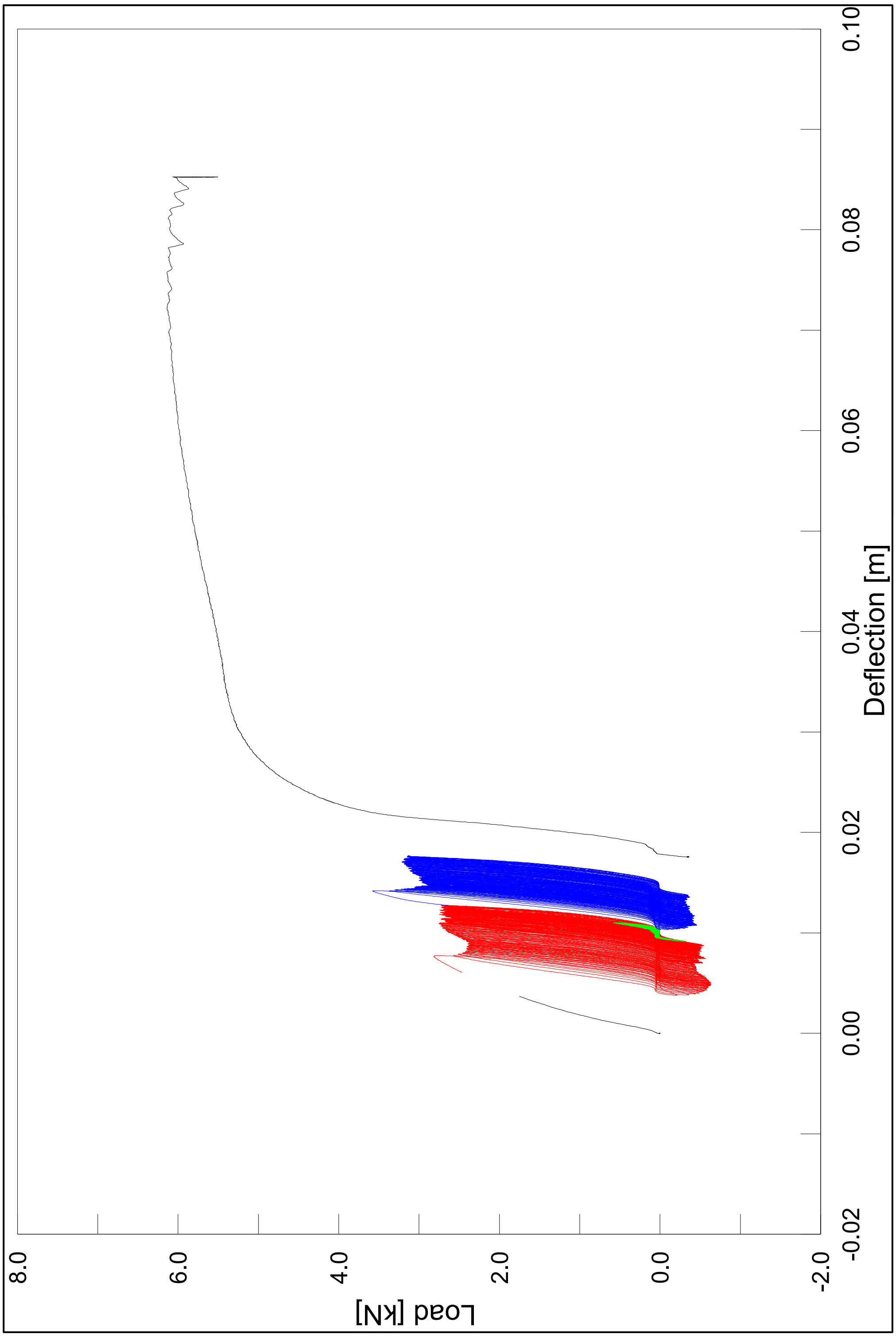
LATERAL LOAD TEST 23-04-2009, TEST 2

Test information		**Preparation:**	
Type	CYCLIC	Date:	23-04-2009
Pile diameter (D)	28 mm	Density,ρ	1646,8 kg/m^3
Embedment length (L)	10, D	Void ratio,e	0,607
Load height (e)	1,429 D	Rel. density, Id	0,811
Scale (N)	68,4		

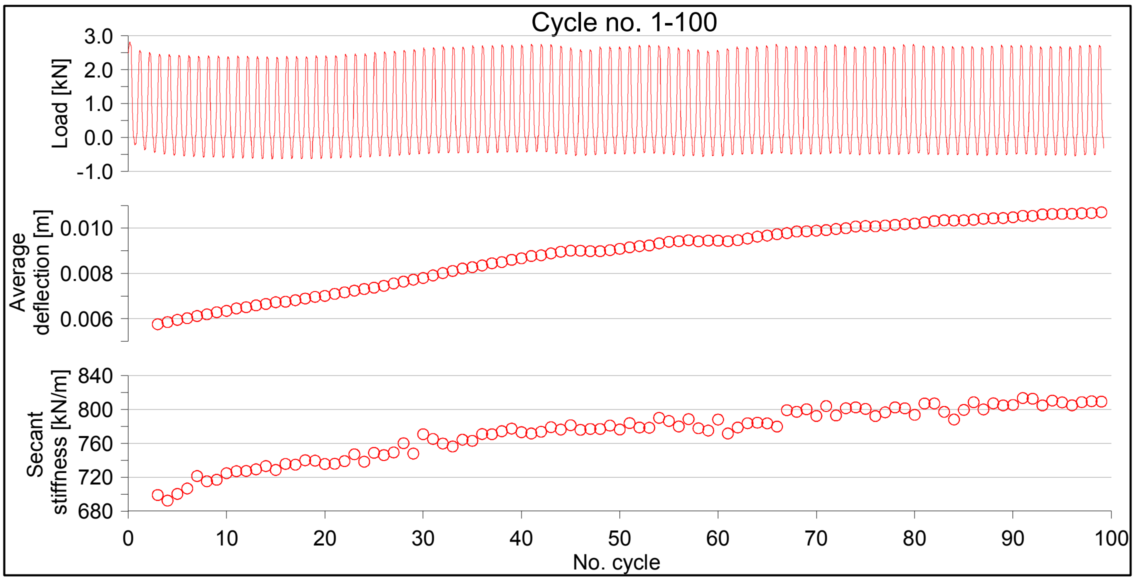
Calibration date:

Novo100	28-02-2008
New LC	30-04-2009

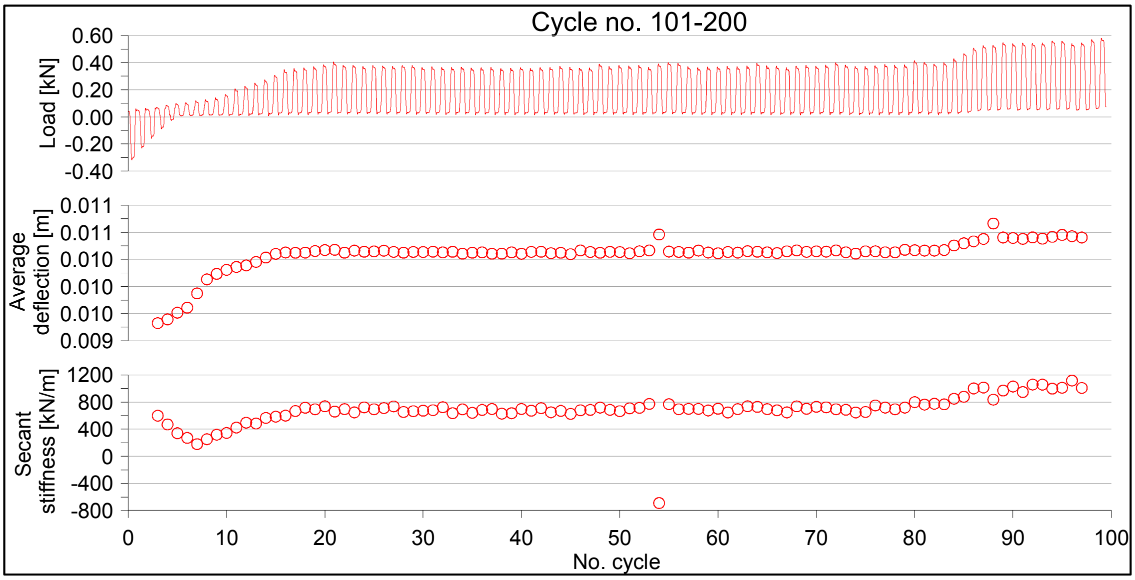
Results are scaled to prototype scale



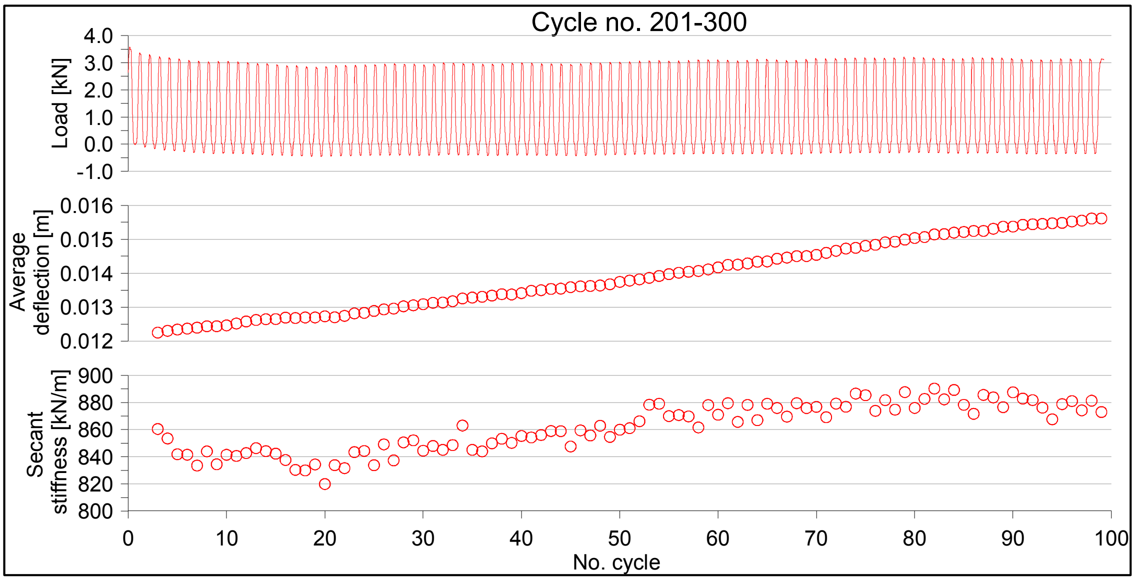
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 19-05-2009

Test information

Type	CYCLIC
Pile diameter (D)	40 mm
Embedment length (L)	6, D
Load height (e)	1 D
Scale (N)	72,4

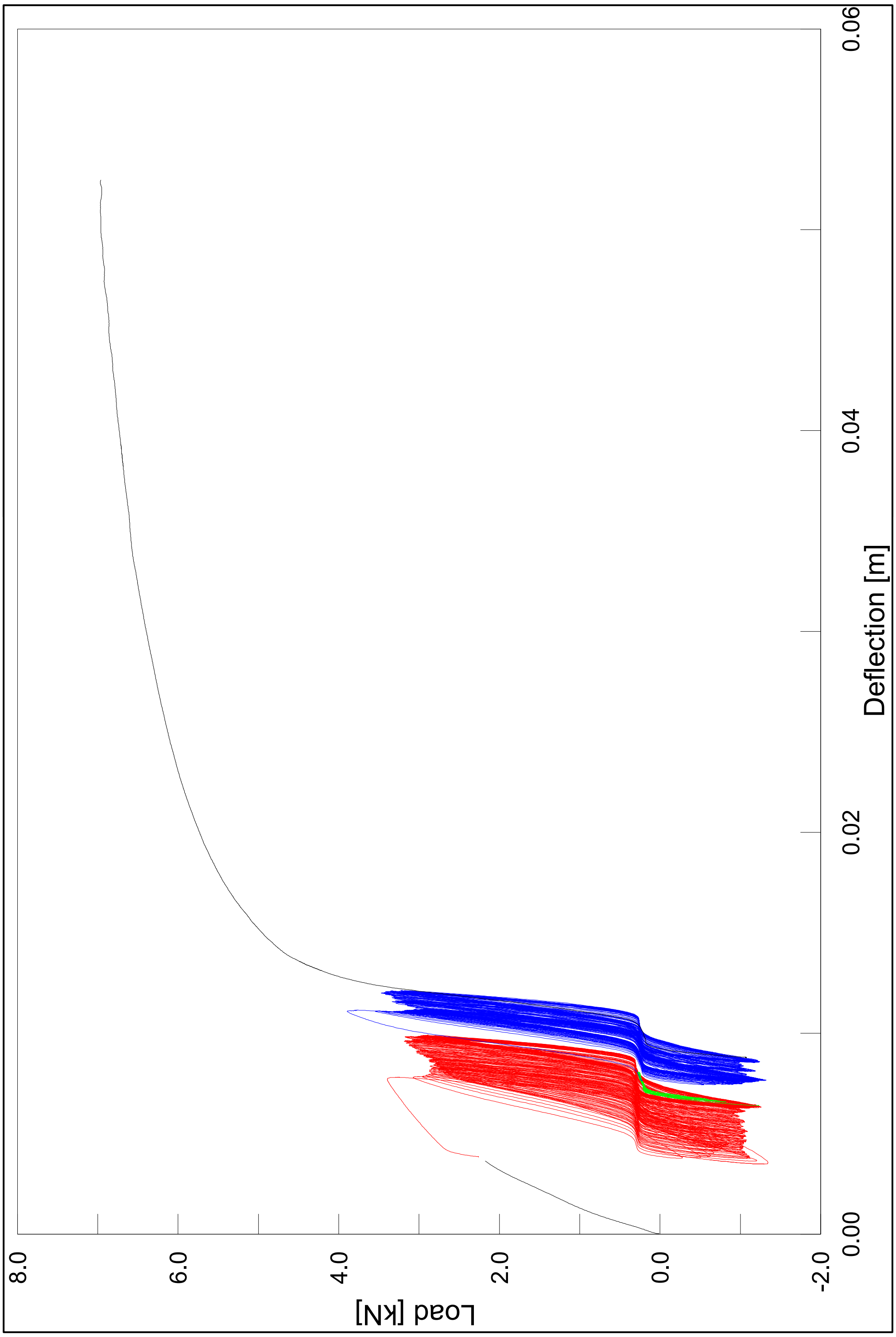
Calibration date:

Novo100	16-12-2008
New LC	30-04-2009

Preparation:

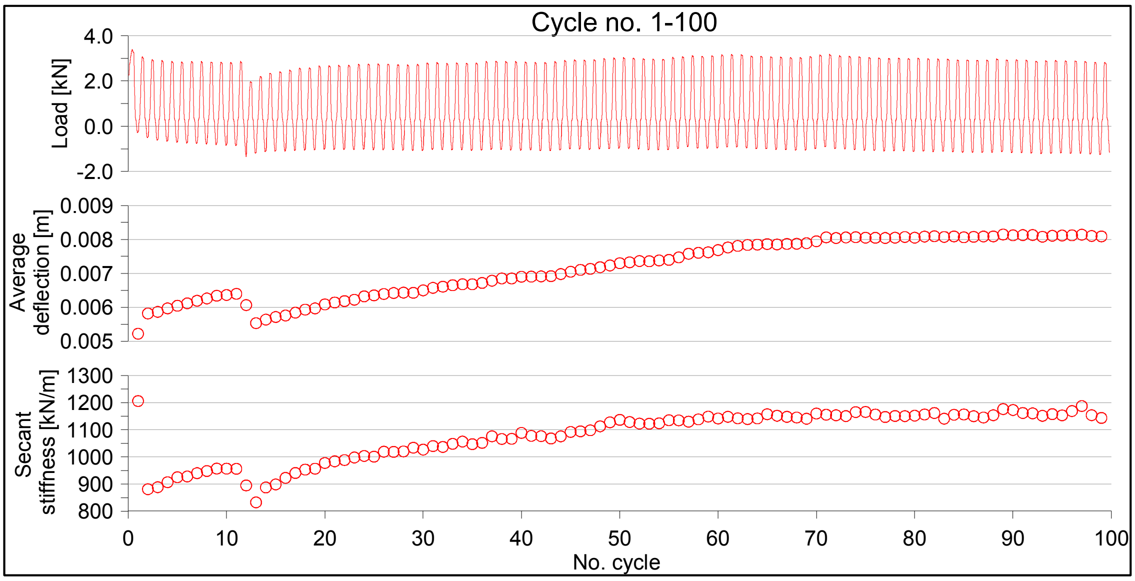
Date:	18-05-2009
Density,ρ	1654,2 kg/m^3
Void ratio,e	0,600
Rel. density, Id	0,834

Reprint of data from Klinkvort (2009b)
Results are scaled to prototype scale

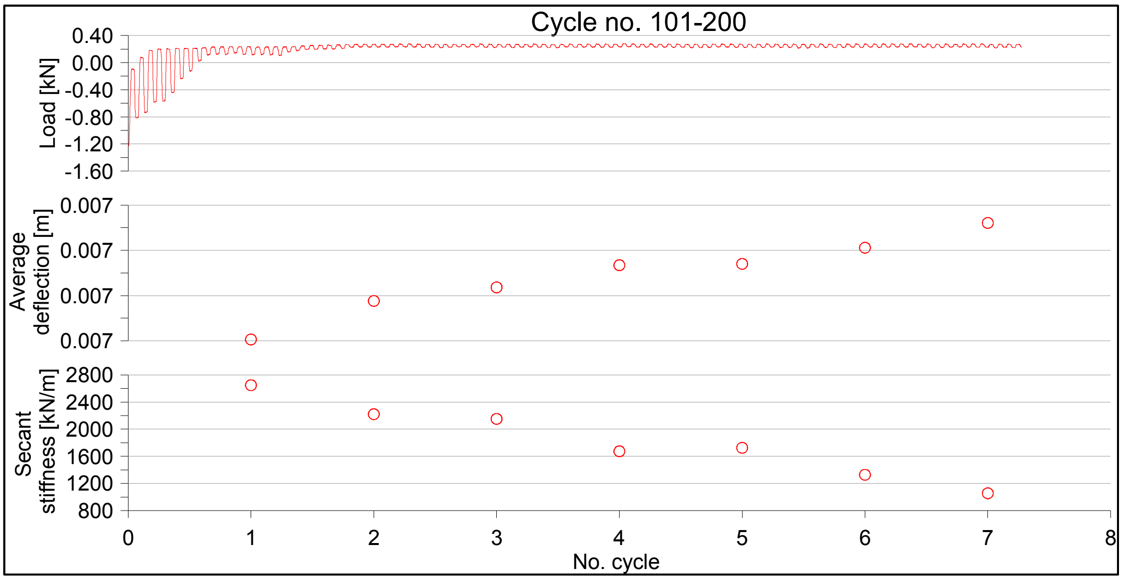


LATERAL LOAD TEST 19-05-2009

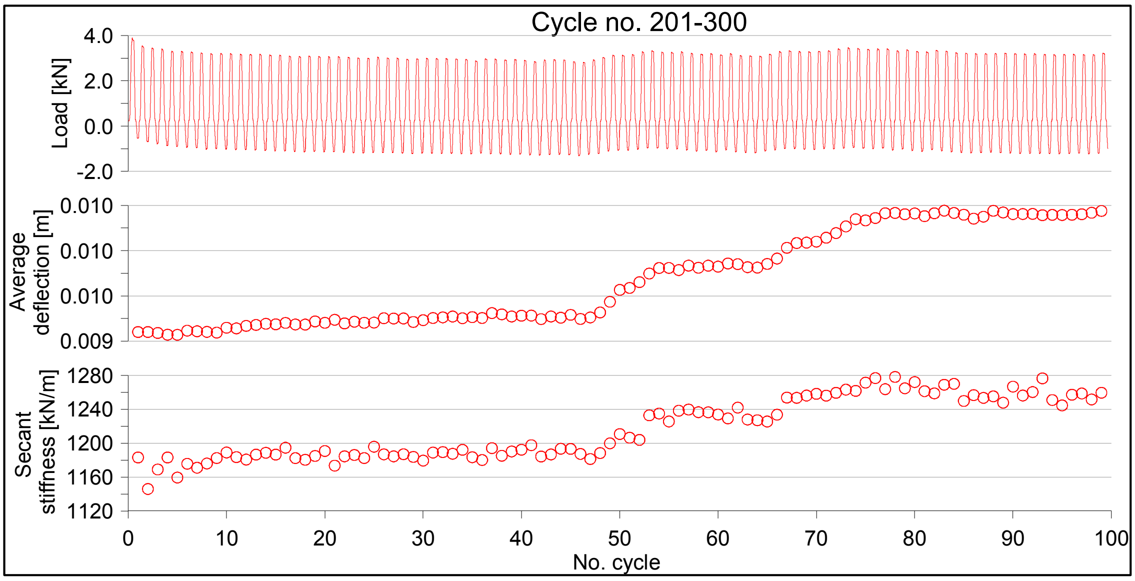
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 04-06-2009

Test information

Type	CYCLIC
Pile diameter (D)	40 mm
Embedment length (L)	8, D
Load height (e)	1 D
Scale (N)	71,6

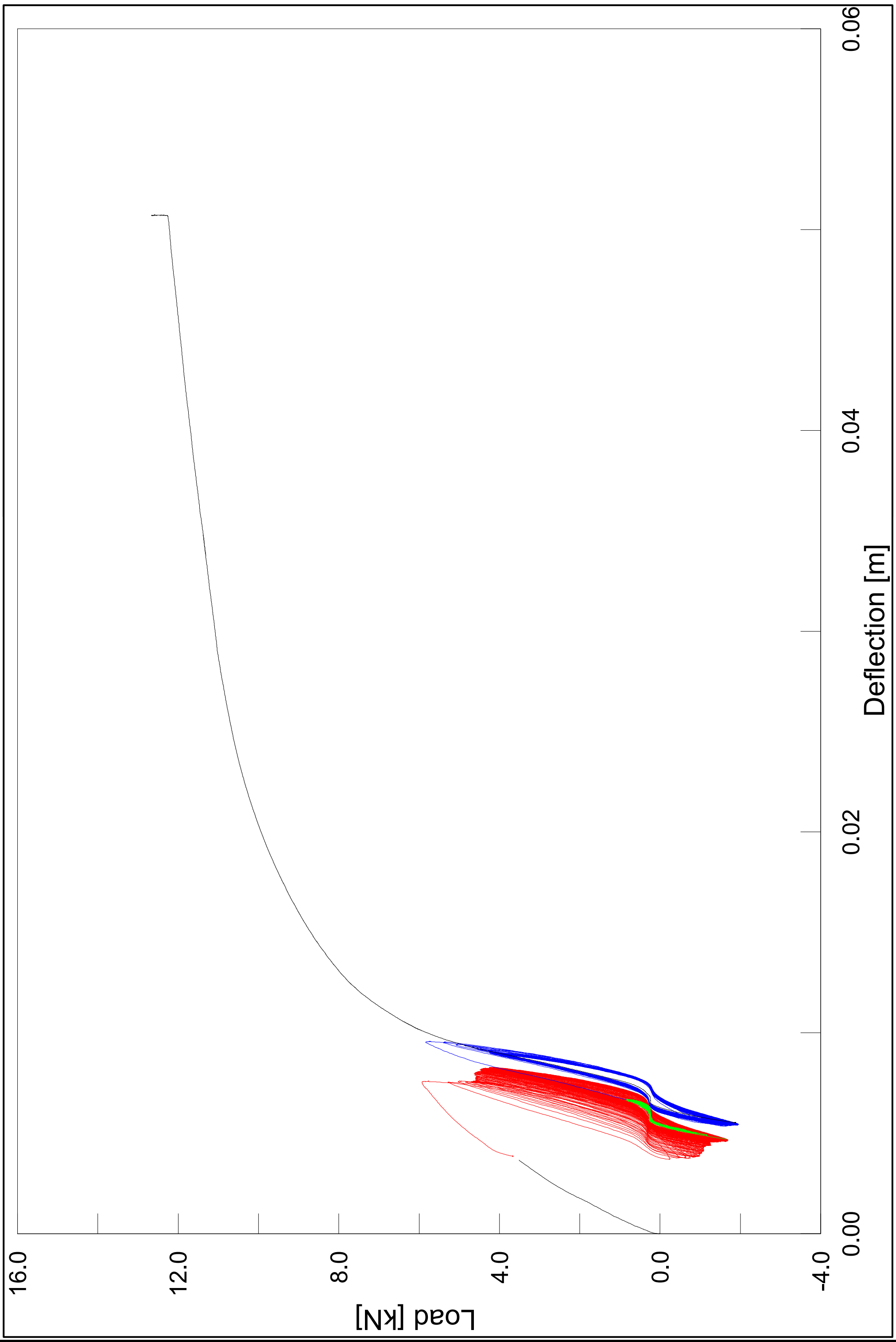
Calibration date:

Novo100	16-12-2008
New LC	30-04-2009

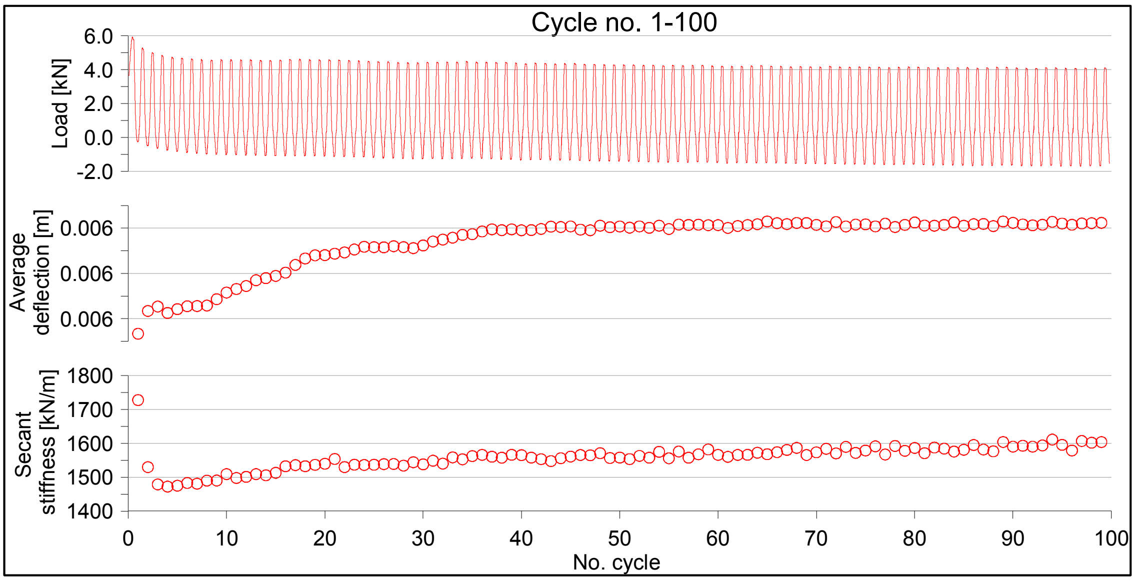
Preparation:

Date:	02-06-2009
Density,ρ	1670,5 kg/m^3
Void ratio,e	0,584
Rel. density, Id	0,884

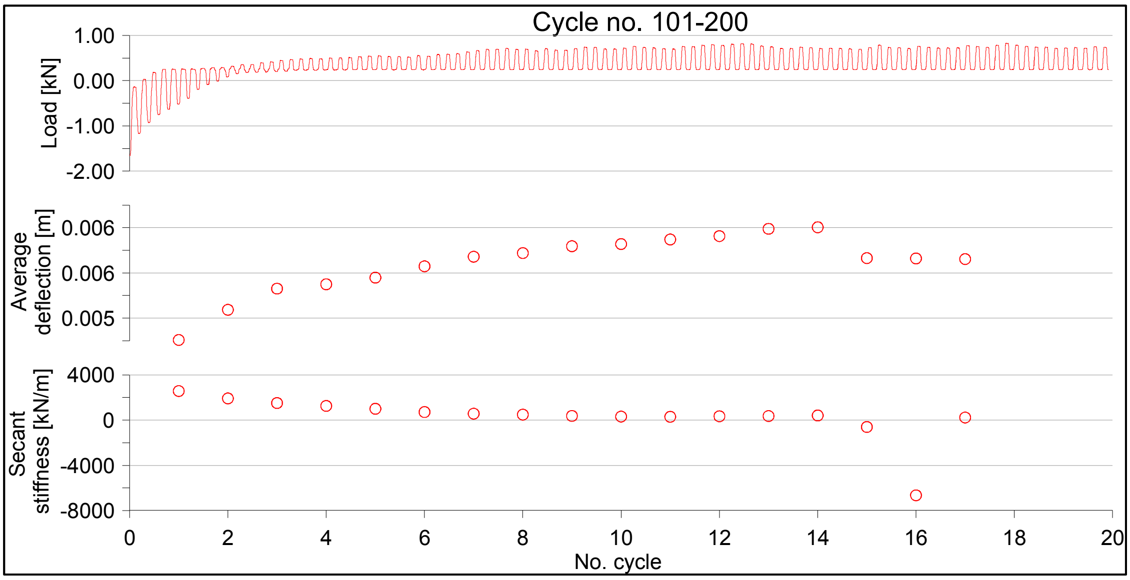
Reprint of data from Klinkvort (2009b)
Results are scaled to prototype scale



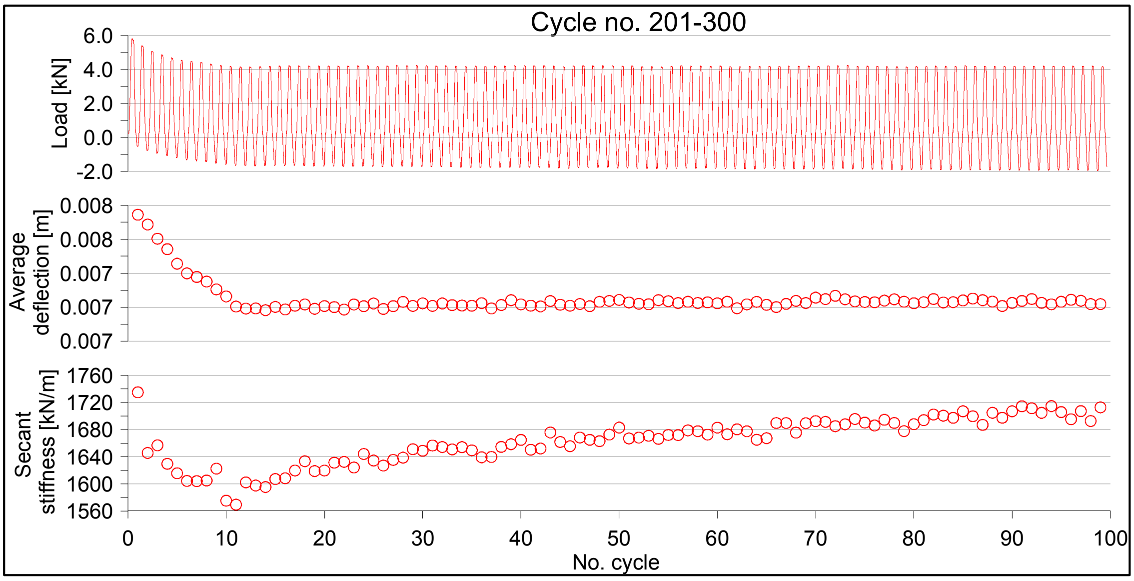
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 28-04-2009, TEST 1	Page 1/2

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	10, D
Load height (e)	2,5 D
Scale (N)	60,9

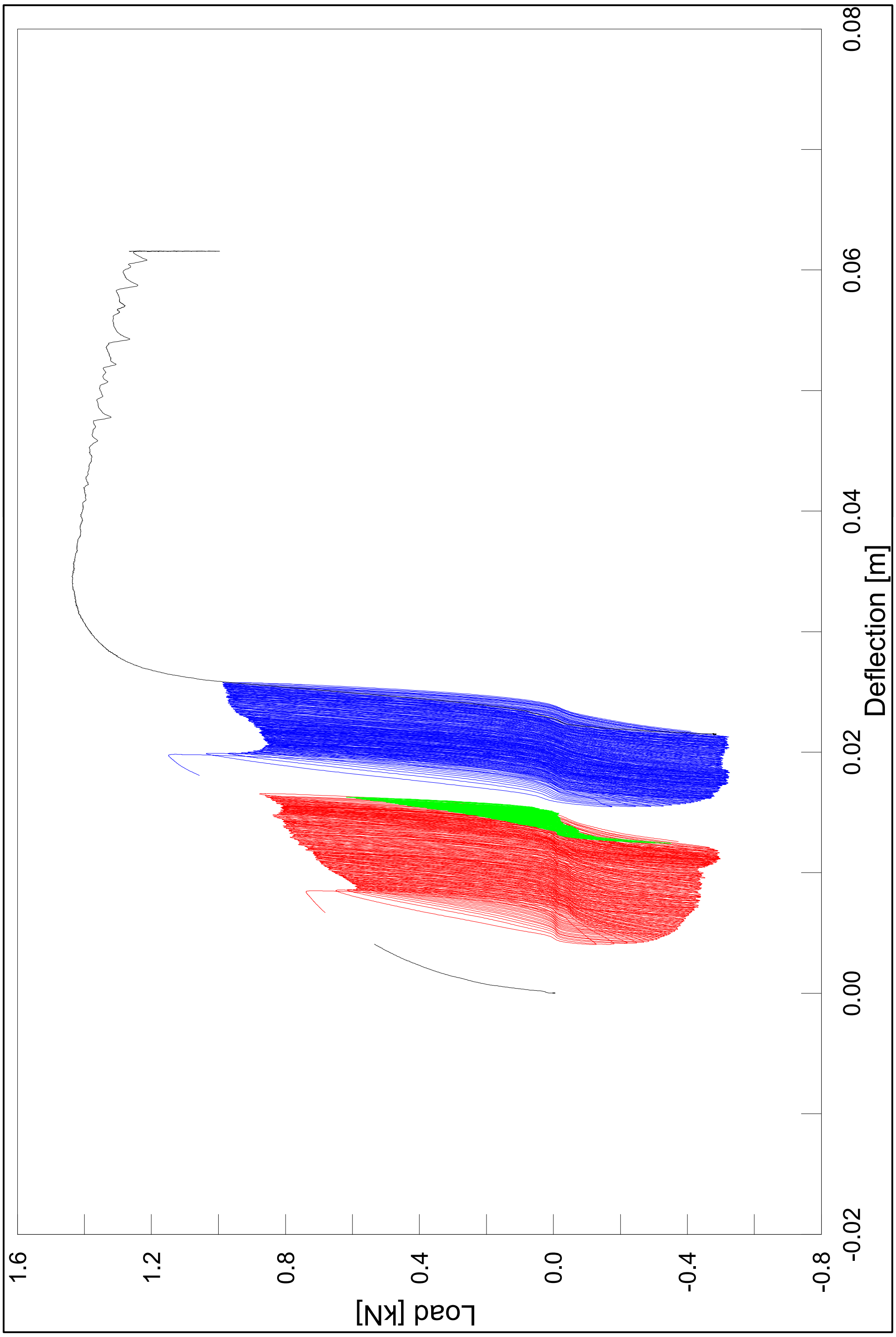
Calibration date:

Novo100	28-02-2008
LC7	30-04-2009

Preparation:

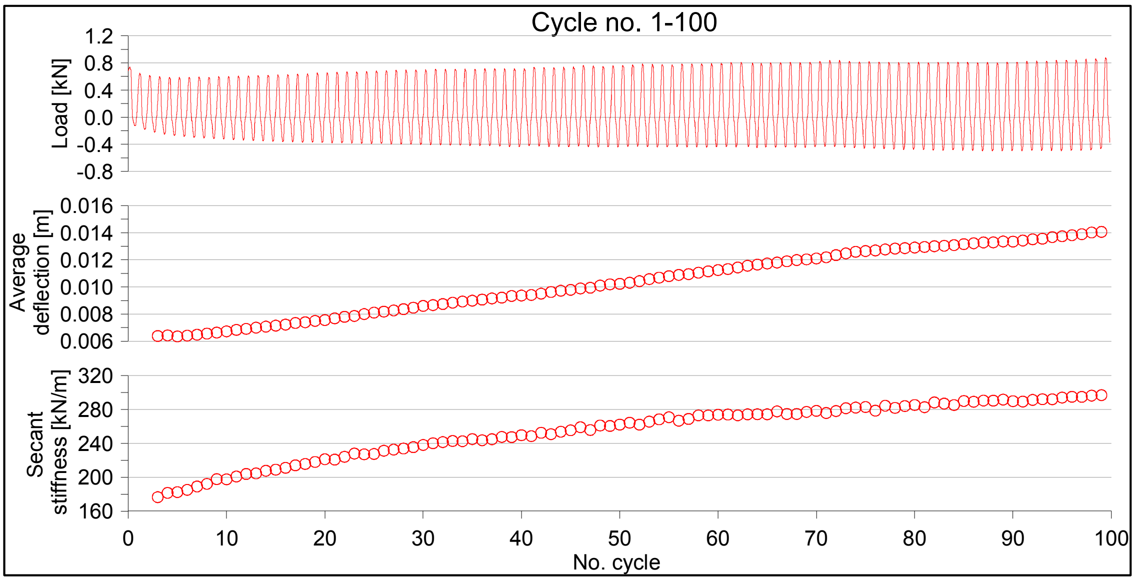
Date:	28-04-2009
Density,ρ	1649,8 kg/m^3
Void ratio,e	0,604
Rel. density, Id	0,82

Results are scaled to prototype scale

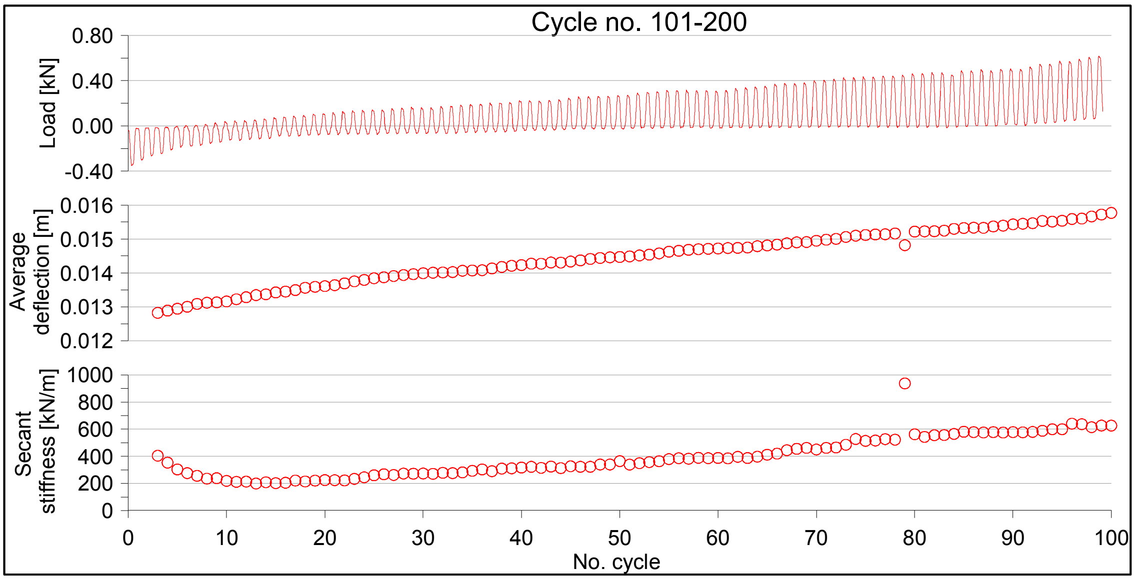


LATERAL LOAD TEST 28-04-2009, TEST 1

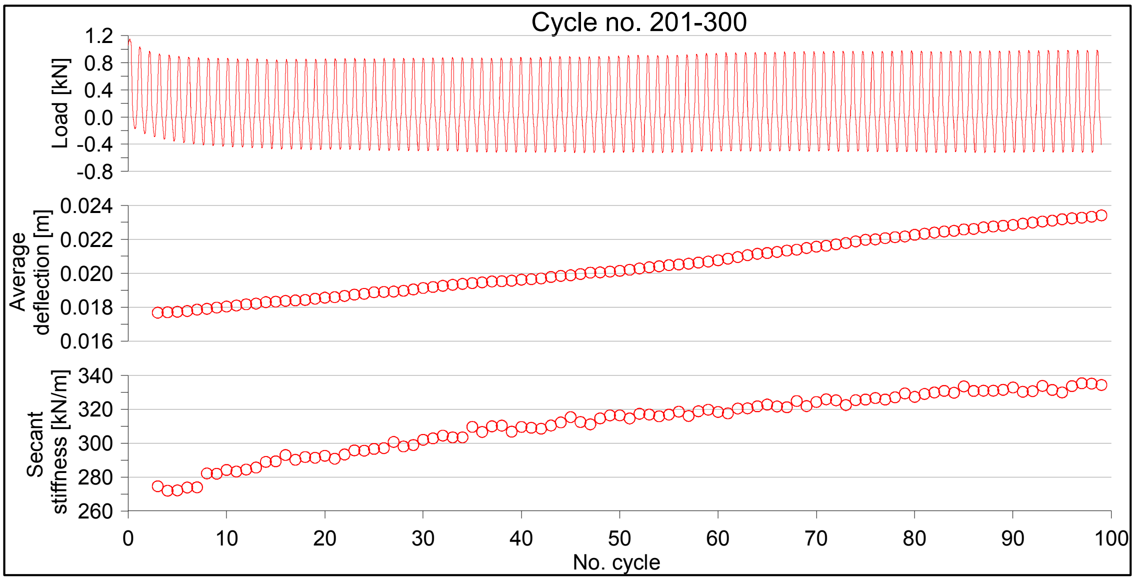
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 28-04-2009, TEST 2	Page 1/2

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	8, D
Load height (e)	2,5 D
Scale (N)	61,2

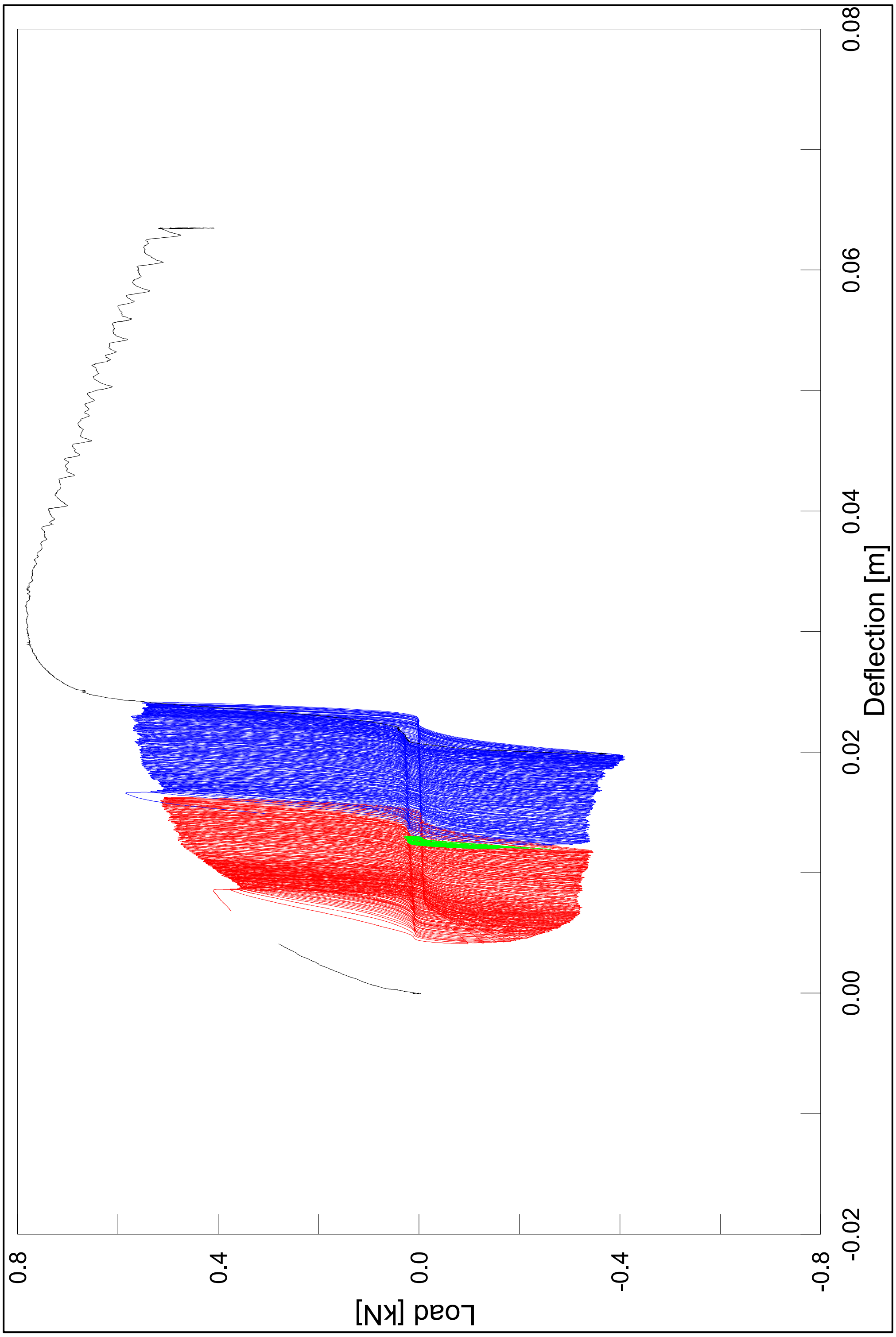
Calibration date:

Novo100	28-02-2008
LC7	30-04-2009

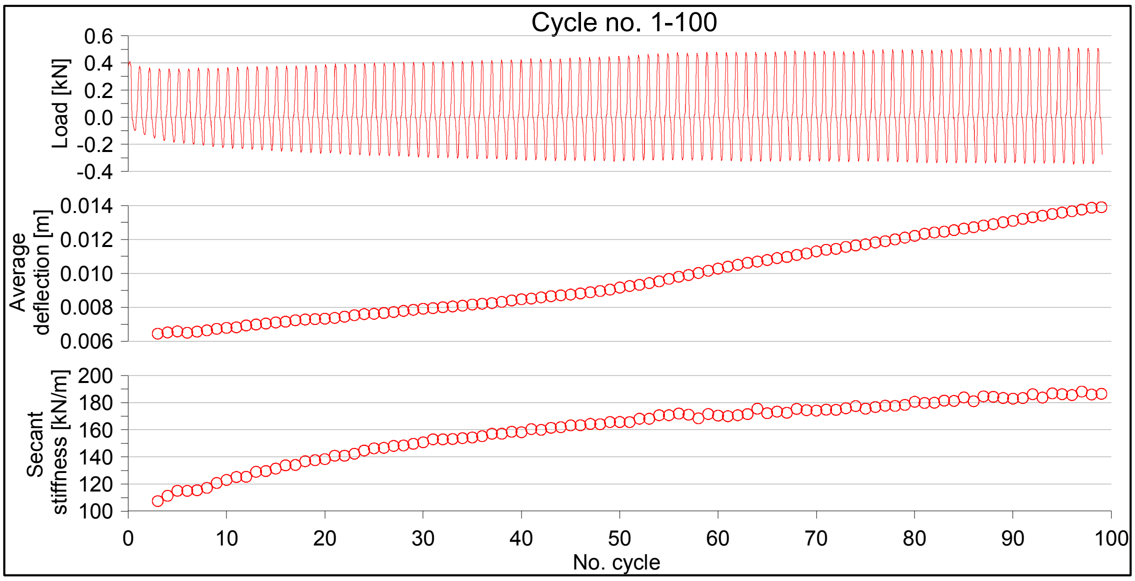
Preparation:

Date:	27-04-2009, 2nd prep.
Density,ρ	1652,1 kg/m^3
Void ratio,e	0,602
Rel. density, Id	0,828

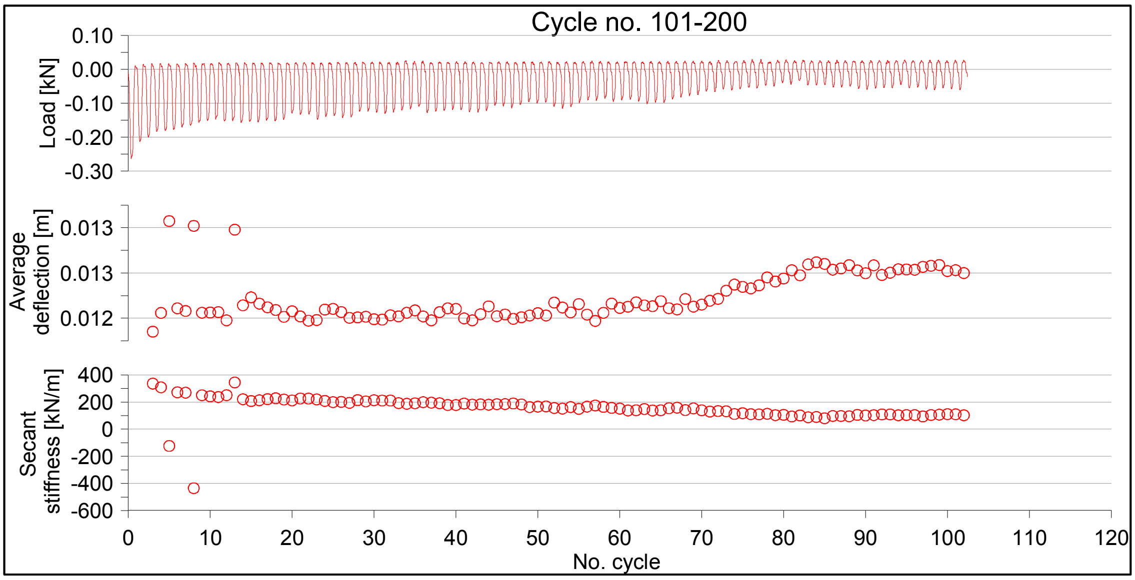
Results are scaled to prototype scale



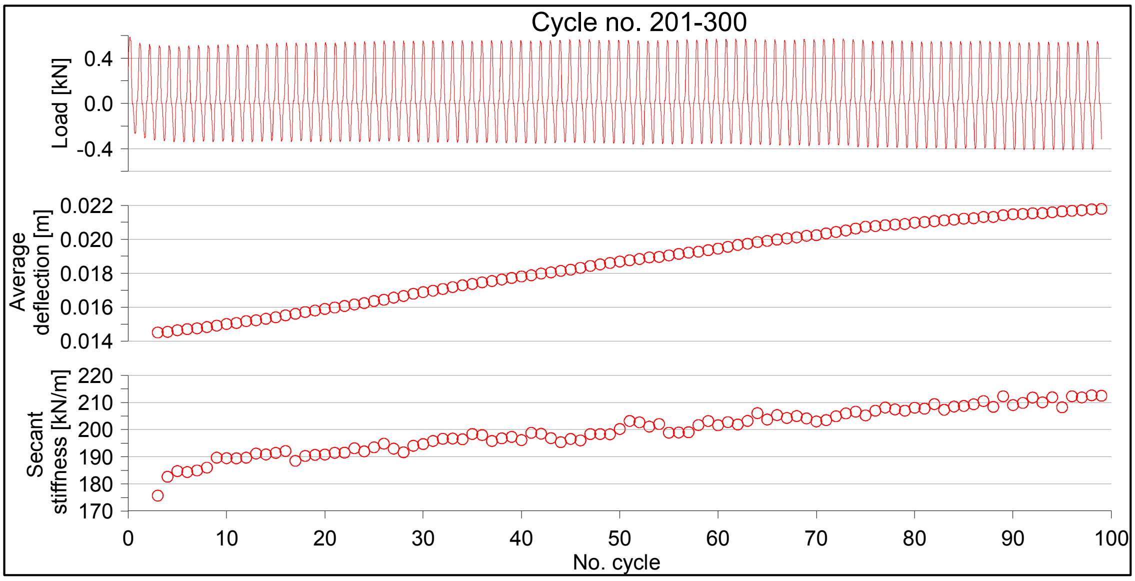
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 29-04-2009

Test information

Type	CYCLIC
Pile diameter (D)	16 mm
Embedment length (L)	6, D
Load height (e)	2,5 D
Scale (N)	61,5

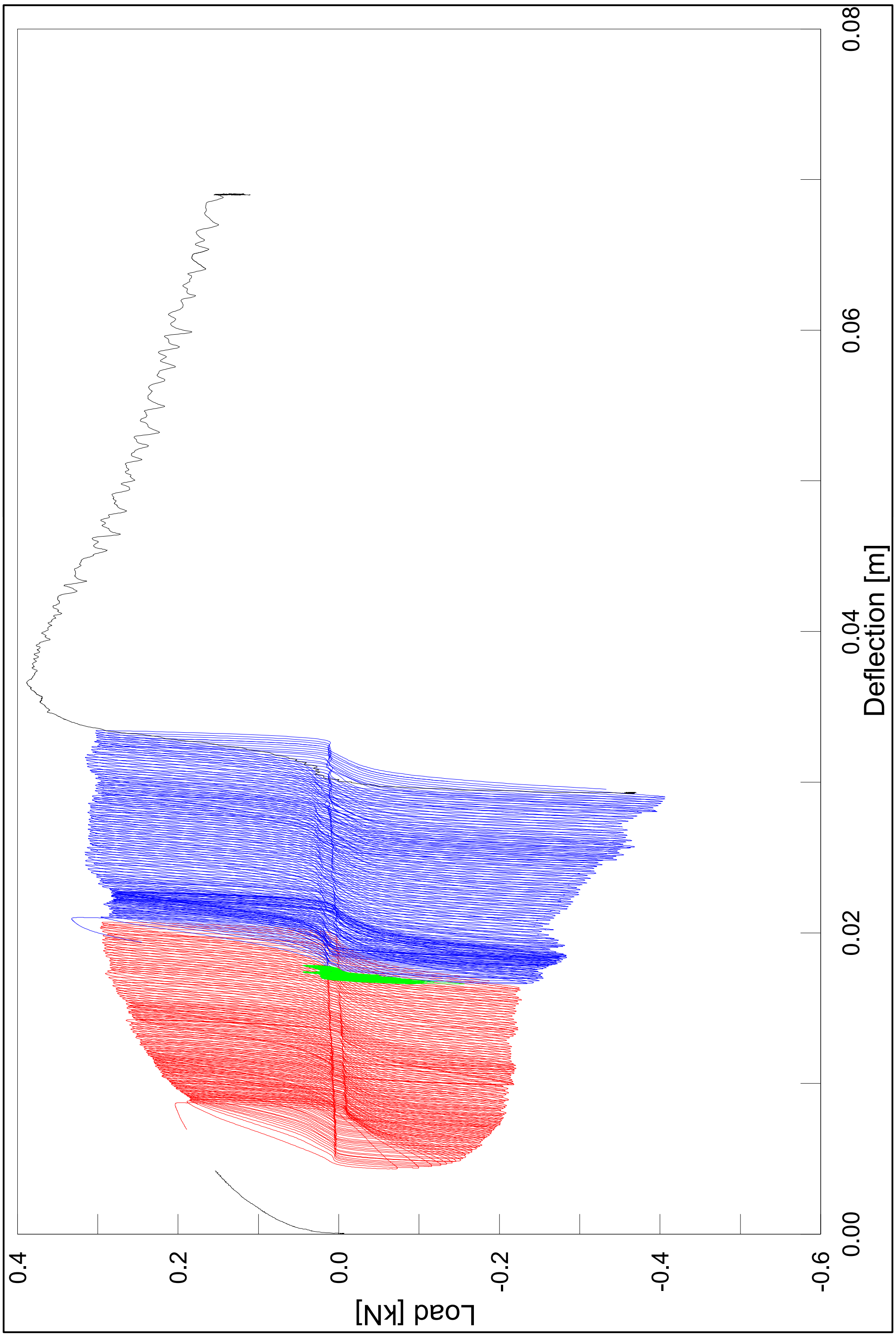
Calibration date:

Novo100	28-02-2008
LC7	30-04-2009

Preparation:

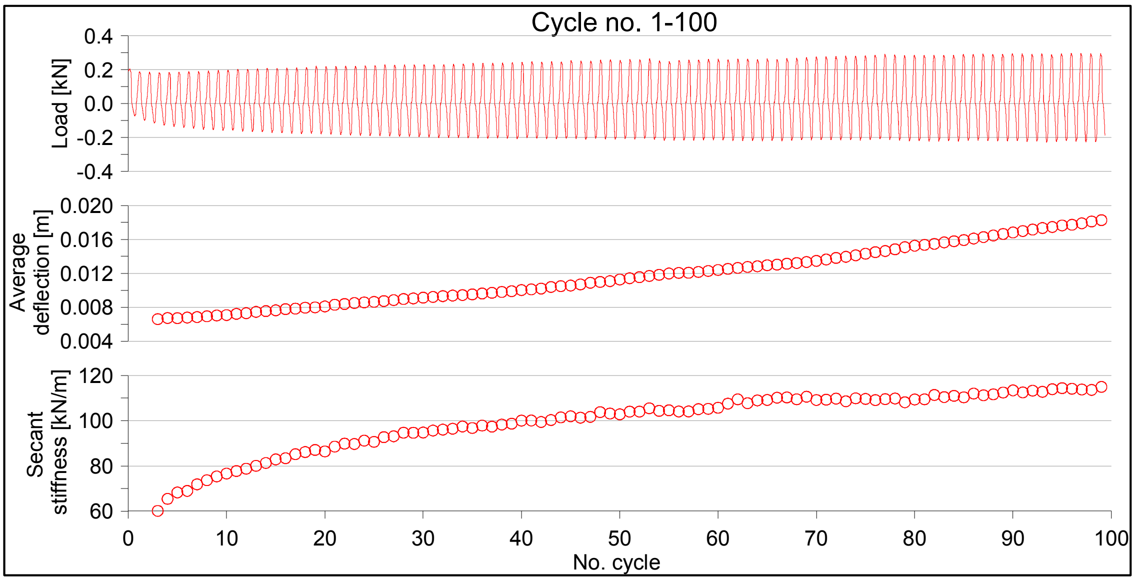
Date:	29-04-2009
Density,ρ	1658,2 kg/m^3
Void ratio,e	0,596
Rel. density, Id	0,847

Results are scaled to prototype scale

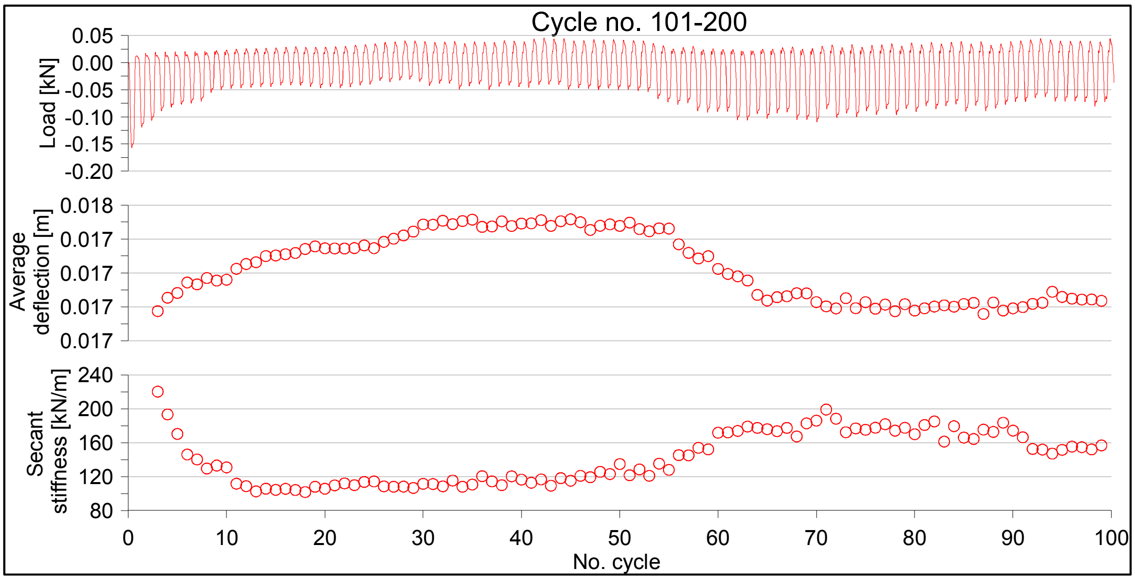


LATERAL LOAD TEST 29-04-2009

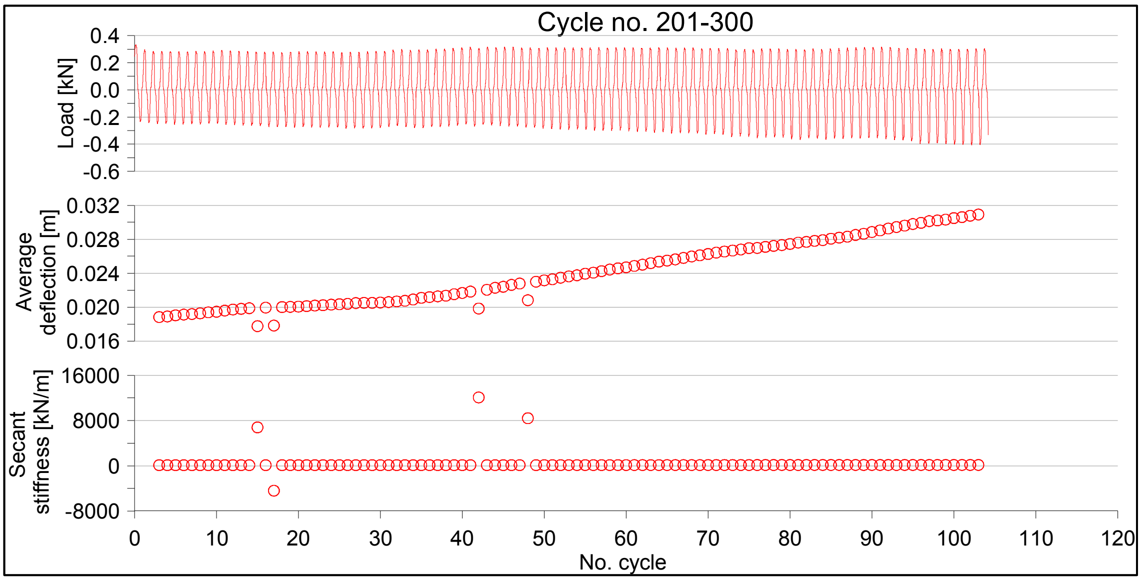
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



LATERAL LOAD TEST 30-04-2009

Test information

Type	CYCLIC
Pile diameter (D)	28 mm
Embedment length (L)	6, D
Load height (e)	1,429 D
Scale (N)	69,5

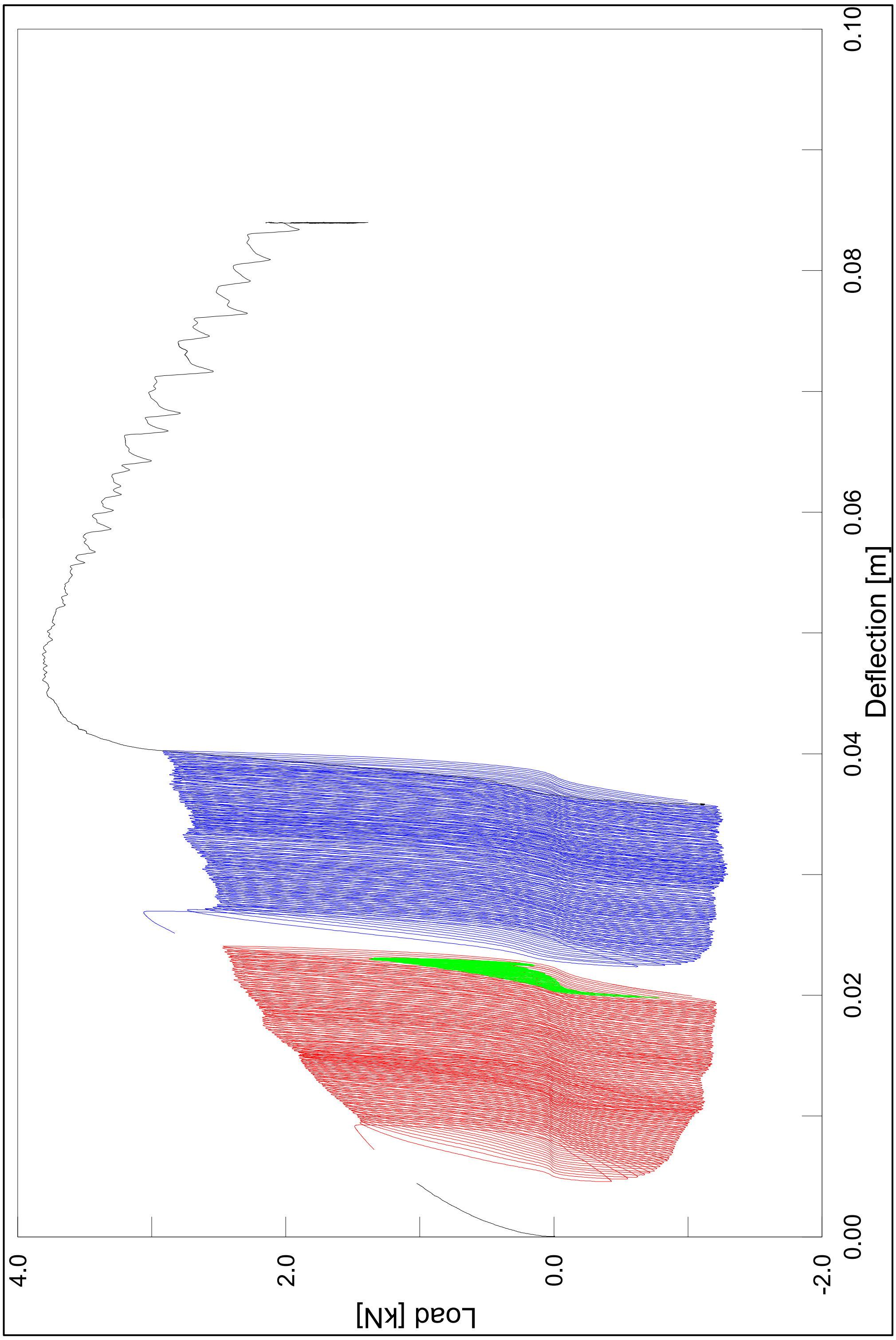
Calibration date:

Novo100	28-02-2008
New LC	30-04-2009

Preparation:

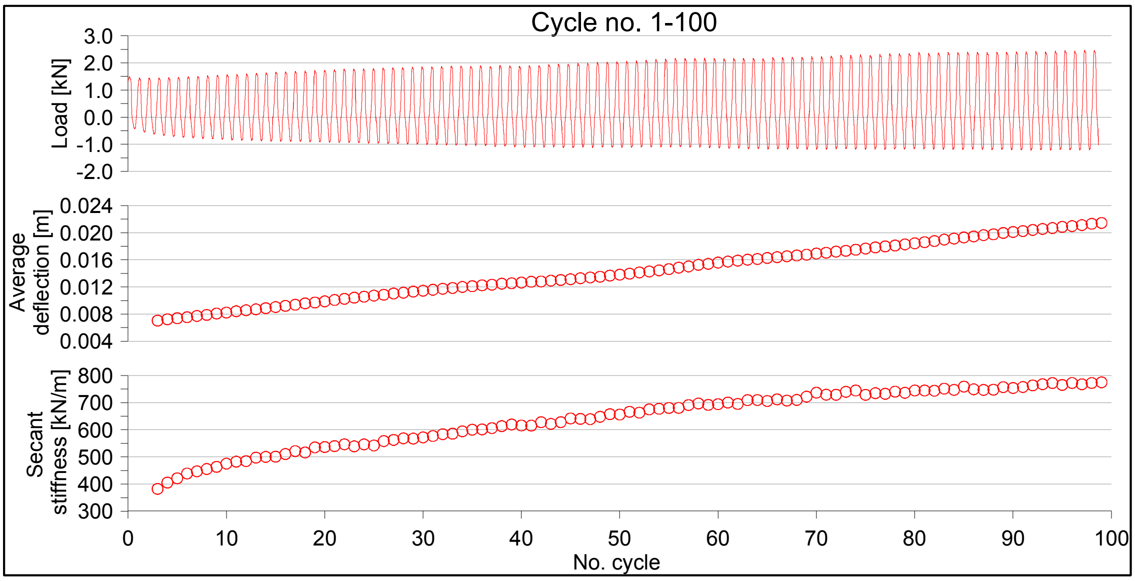
Date:	30-04-2009
Density,ρ	1663,3 kg/m^3
Void ratio,e	0,591
Rel. density, Id	0,862

Results are scaled to prototype scale

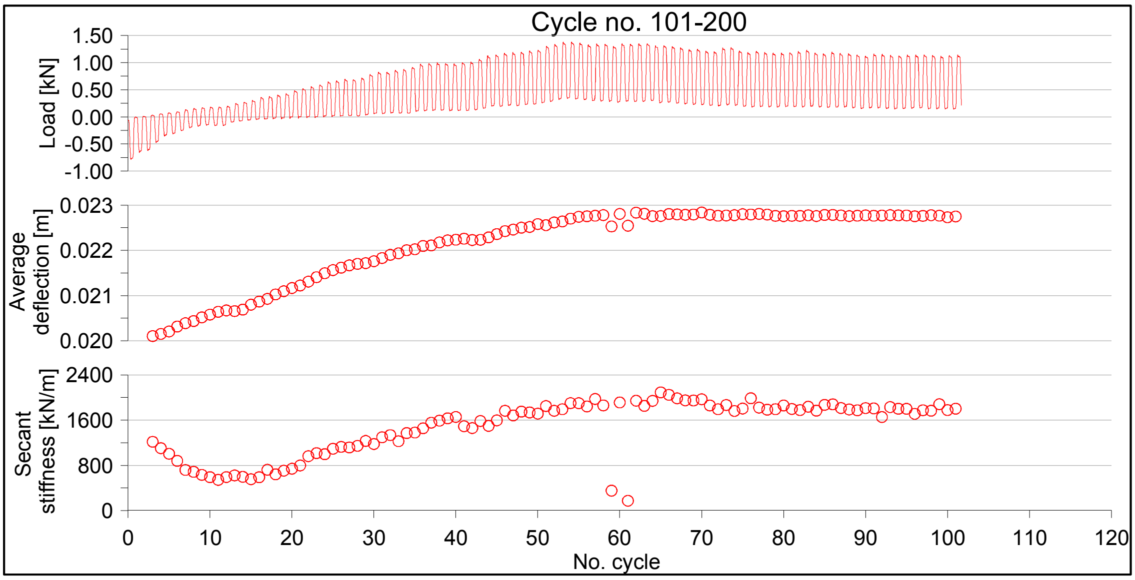


LATERAL LOAD TEST 30-04-2009

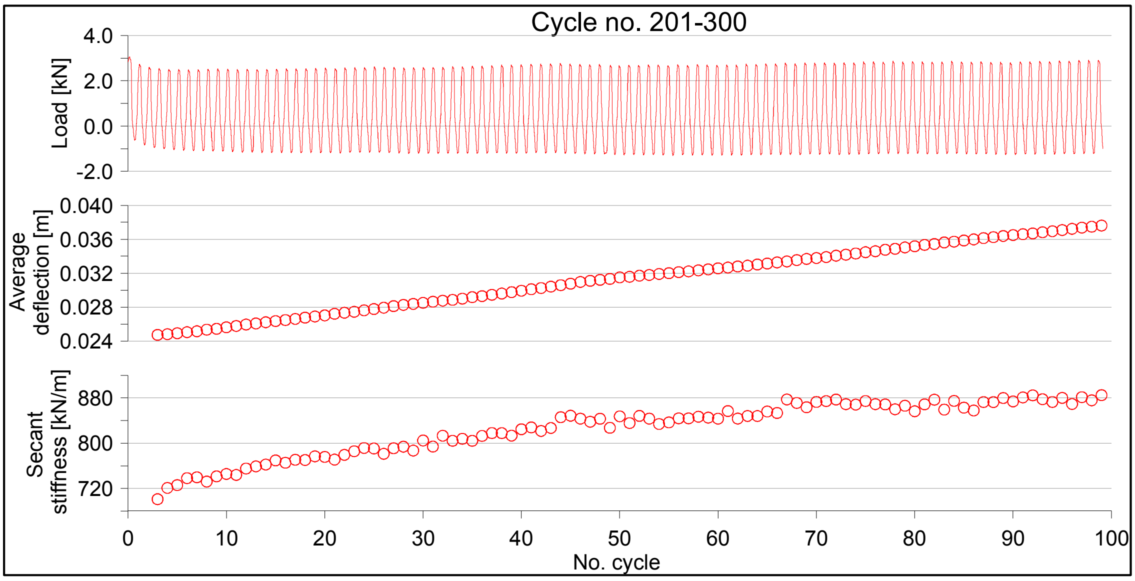
Large cycles, cycle 1-100



Small cycles, cycle 101-200



Large cycles, cycle 201-300



Appendix C Data report by Rasmus Klinkvort: *Tværbelastning af monopæl. Geoteknisk datarapport*.

Appendix with Danish data report on lateral load tests on piles with a diameter of 3 m. Total of 7 pages (excluding this).

DTU Byg
Institut for Byggeri og Anlæg

Tværbelastning af monopæl

Geoteknisk datarapport

Rasmus Klinkvort

7/2/2009

Fire centrifugeforsøg udført i tørt Fontainebleau sand. To statiske og to cykliske

Indhold

Generel beskrivels: 3
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Beskrivelse: 5
Sanddata: 5
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Kommentarer: 5
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Generel beskrivels:

Der er i perioden 14/05/2009 til 02/06/2009 blevet udført fire modelforsøg i den geotekniske centrifuge på DTU-Byg. Der er foretaget forsøg med tværbelastning af en monopæl to statiske og to cykliske, alle forsøg er udført af Rasmus Klinkvort. Forsøgende er udført i tørt Fontainebleau sand. Alle værdier præsenteret her er prototype værdier. Det vil sige at flytninger er skaleret med faktor N og kræfter er skaleret med faktor N^2. Skaleringsfaktoren N er fundet ud fra omdrejningstallet for centrifugen i tredjedelspunktet af pælen. Skaleringslove, forsøgs opstilling osv. er beskrevet i (Klinkvort, 2009). For alle forsøg kan der regnes med en skaleringsfaktor på N=75.

De statiskforsøg er kørt til brud. De cykliske forsøg er kørt med en serie med 100 cykler med stor amplitude 100 cykler med den halve amplitude og 100 cykler med stor amplitude igen.

I hele rapporten vil pælediameteren betegnes som D, Lastexcentricitet H og penetrationsdybden L.

Kalibrerings konstanter:

Kraft cellen:	-2,3486 kN/V	(kalibreret 30/04/2009 af CTL)
LVDT:	-10,2910 mm/V	(kalibreret 16/12/2008 af RTK)

D=40mm & H=1D & L=6D

Beskrivelse:

Der er foretaget to forsøg på pæl med model dimensioner diameter D=40mm penetrations dybde L=240mm (6D) og last excentricitet H=40mm (1D). Der er foretaget et statisk forsøg til brud og et cyklisk forsøg.

Sanddata:

	Statisk forsøg	Cyklisk forsøg
ID [%]	0,915	0,908
e [-]	0,574	0,577
ϕ [^{o}]	42,2	42,0
γ [kN/m^3]	16,8	16,8

Forsøgsdata:

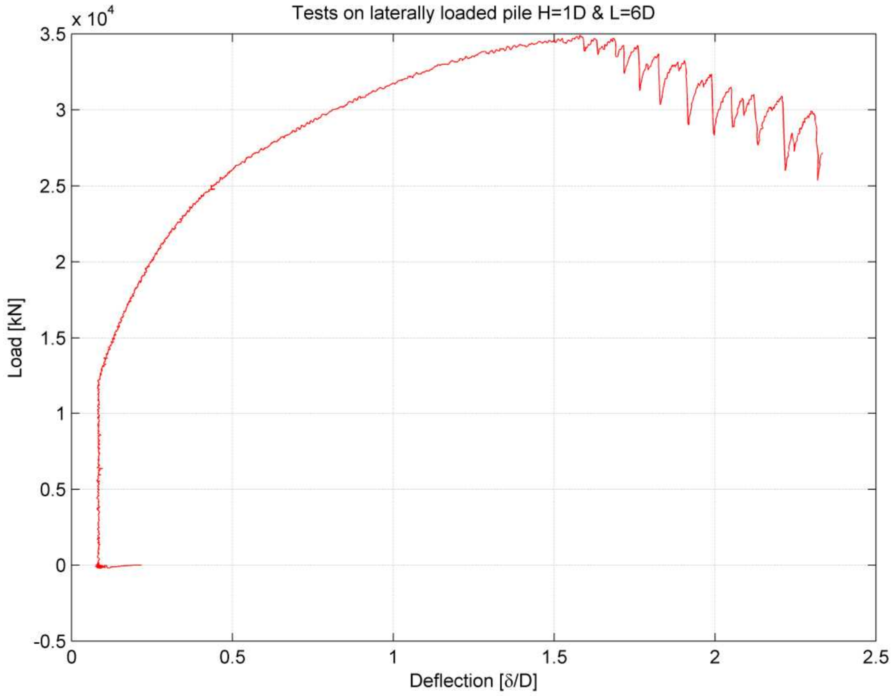
Se næste side Figur 1 og

Kommentarer:

På det statiske forsøg var LVDTen blevet placeret i en yderposition der bevirkede at de indlederne deformationer ikke blev registreret. Dette ses på det statiske forsøg Figur 1 som en lodret linje indtil omkring 12500kN.

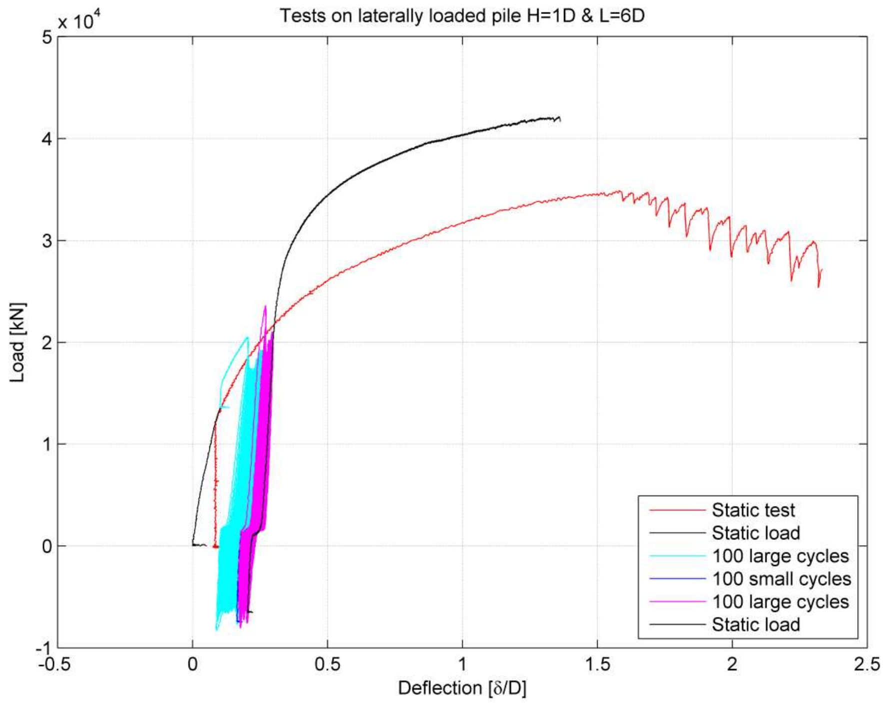
Det ses efterfølgende på det cykliske forsøg Figur 2 at den del af kurven som ikke blev beskrevet ved det statiske forsøg. Bliver beskrevet i det cykliske forsøgs oplastning til udgangspunkts niveau for de første cykler. Hermed er hele den statiske kurve beskrevet som ønsket.

Statisk forsøg:



Figur 1

Cyklisk forsøg:



Figur 2

D=40mm & H=1D & L=8D

Beskrivelse:

Der er foretaget to forsøg på pæl med model dimensioner diameter D=40mm penetrations dybde L=320mm (8D) og last excentricitet H=40mm (1D). Der er foretaget et statisk forsøg til brud og et cyklisk forsøg.

Sanddata:

	Statisk forsøg	Cyklisk forsøg
ID [%]	0,944	0,958
e [-]	0,565	0,561
ϕ [^{o}]	42,6	42,8
γ [kN/m^3]	16,9	16,9

Forsøgsdata:

Se næste side Figur 3 og Figur 4

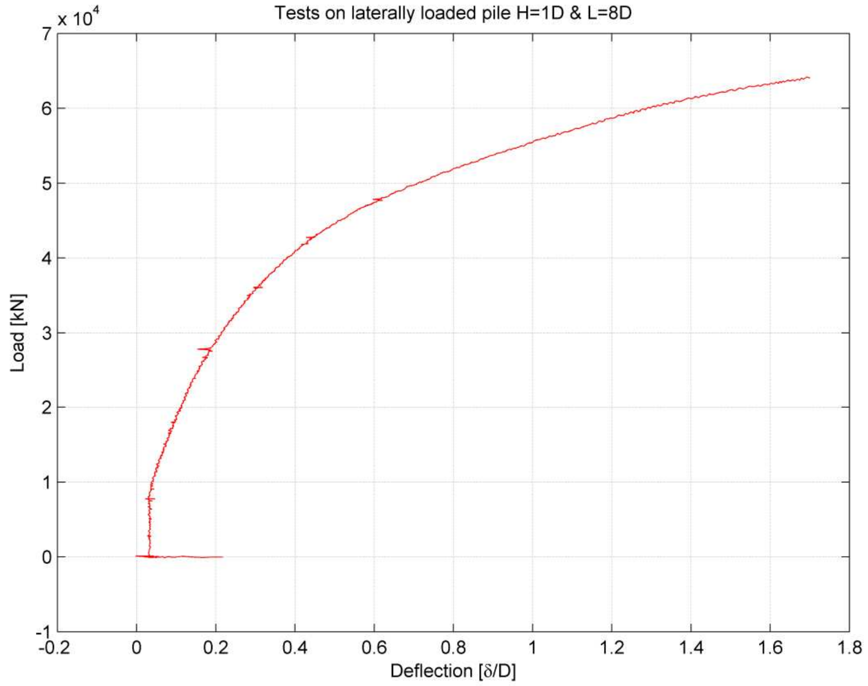
Kommentarer:

På det statiske forsøg var LVDTen blevet placeret i en yderposition der bevirkede at de indlederne deformationer ikke blev registreret. Dette ses på det statiske forsøg Figur 3 som en lodret linje indtil omkring 7000kN

Det ses efterfølgende på det cykliske forsøg Figur 4 at den del af kurven som ikke blev beskrevet ved det statiske forsøg. Bliver beskrevet i det cykliske forsøgs oplastning til udgangspunkts niveau for de første cykler. Hermed er hele den statiske kurve beskrevet som ønsket.

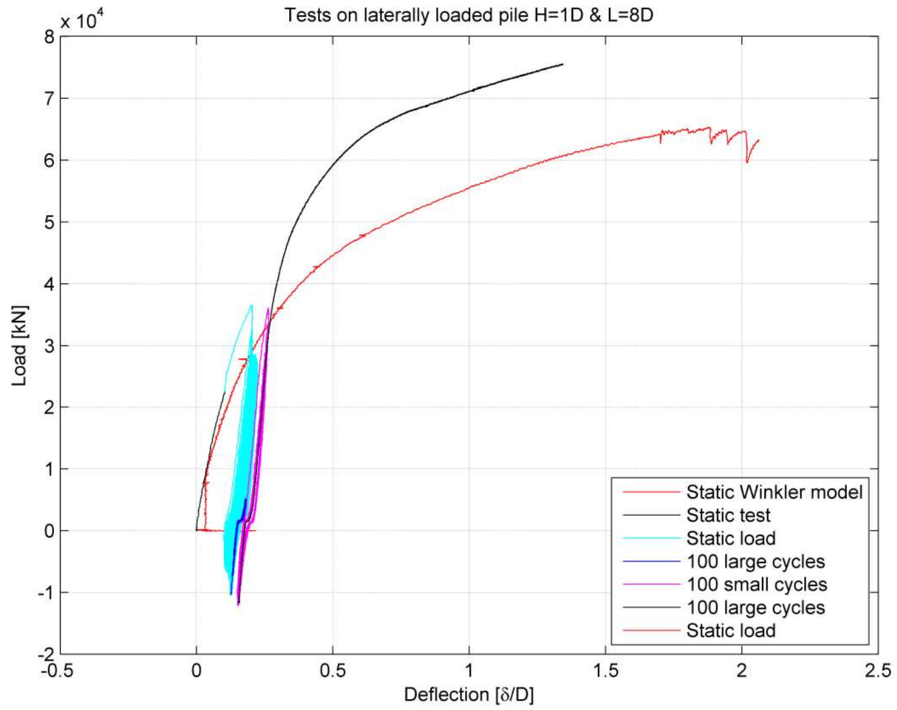
Det virker som at noget er gået galt ved de 100 cykler med små amplitude.

Statisk forsøg:



Figur 3

Cyklisk forsøg:



Figur 4

Bibliography

Klinkvort, R. T. (2009). *LATERALLY LOADED PILES - centrifuge and numerical modelling.* Technical University of Denmark.

Appendix D   Sieve analyses on Fontainebleau sand.

Appendix with results from sieve analyses on Fontainebleau sand. Total of 4 pages (excluding this).

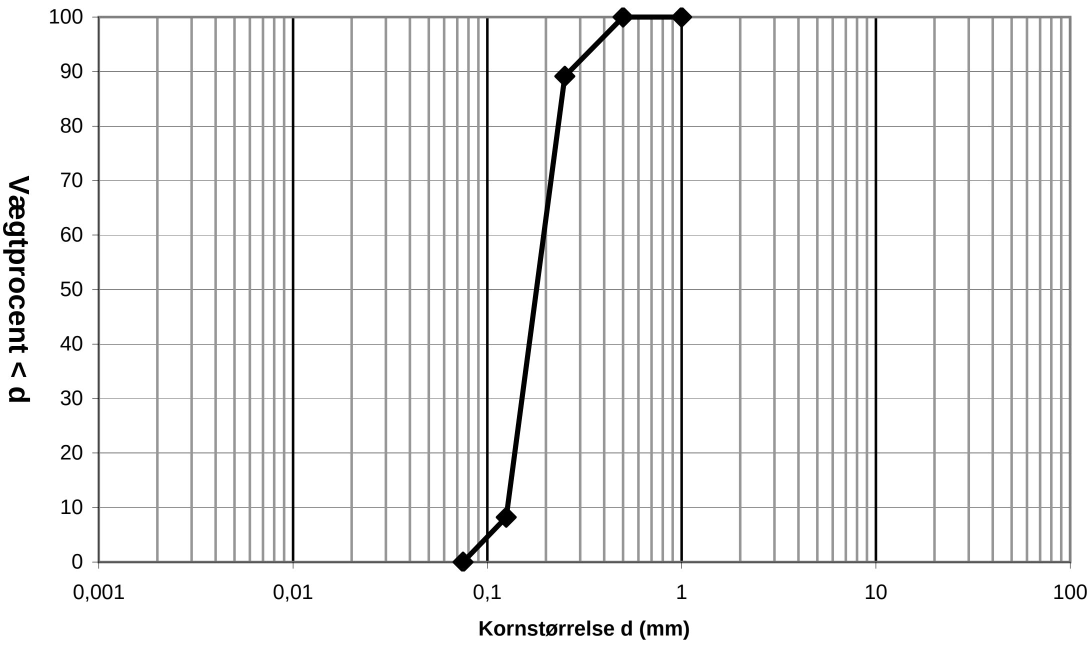
Test sheet test for : Sieve analysis

Sieve analysis 1

Bowl	[g]	218,95
Bowl + sand (prior to sieve analysis)	[g]	360,27
Sand	[g]	141,32

	Mesh size [mm]	Weight [g]	passing [g]	passing [%]
Sieve 1mm	1	0	141,35	100
Sieve 0.50 mm	0,5	0,02	141,33	100
Sieve 0.25 mm	0,25	15,33	126	89
Sieve 0.125 mm	0,125	114,34	11,66	8
Sieve 0.075 mm	0,075	11,55	0,11	0
Bottom sieve	0	0,11	0,00	0
Total		141,35		

Grain size:	d_{60} %	0,20
Non-uniform no.	$U=d_{60}$	1,6



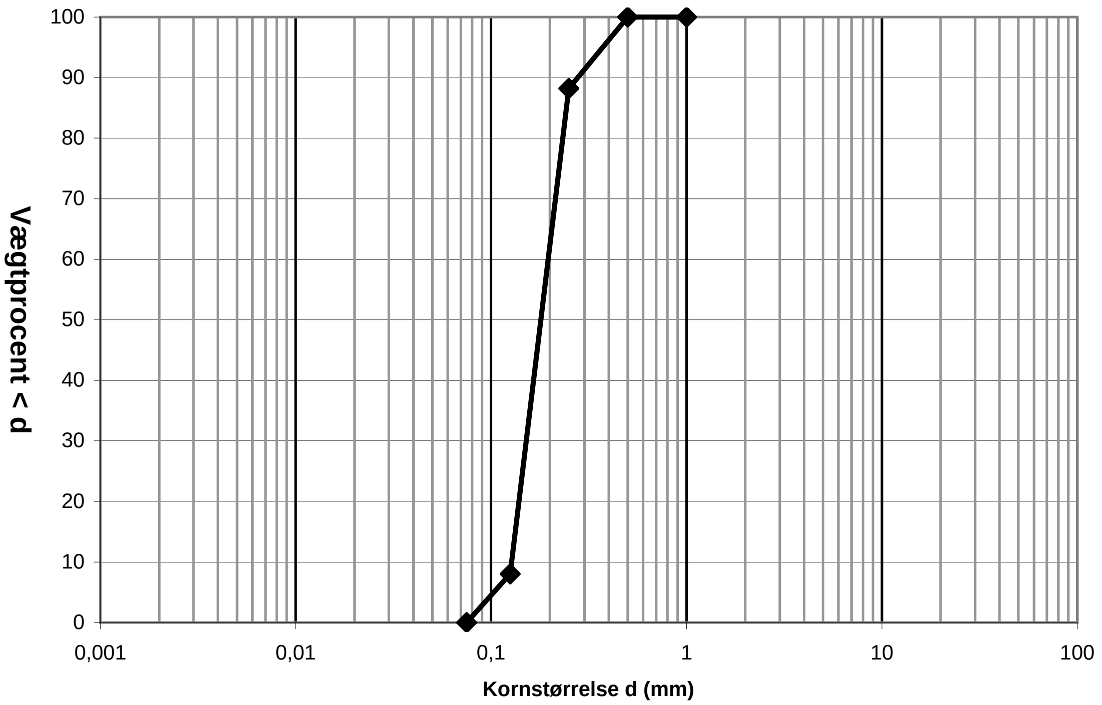
Test sheet test for : Sieve analysis

Sieve analysis 2

Bowl		[g]	220,8
Bowl + sand (prior to sieve analysis)		[g]	362,58
Sand		[g]	141,78

	Mesh size [mm]	Weight [g]	passing [g]	passing [%]
Sieve 1mm	1	0	141,69	100
Sieve 0.50 mm	0,5	0,01	141,68	100
Sieve 0.25 mm	0,25	16,67	125,01	88
Sieve 0.125 mm	0,125	113,65	11,36	8
Sieve 0.075 mm	0,075	11,23	0,13	0
Bottom sieve	0	0,13	0,00	0
Total		141,69		

Grain size:	d_{60} %	0,21
Non-uniform no.	U=d_{60}	1,6



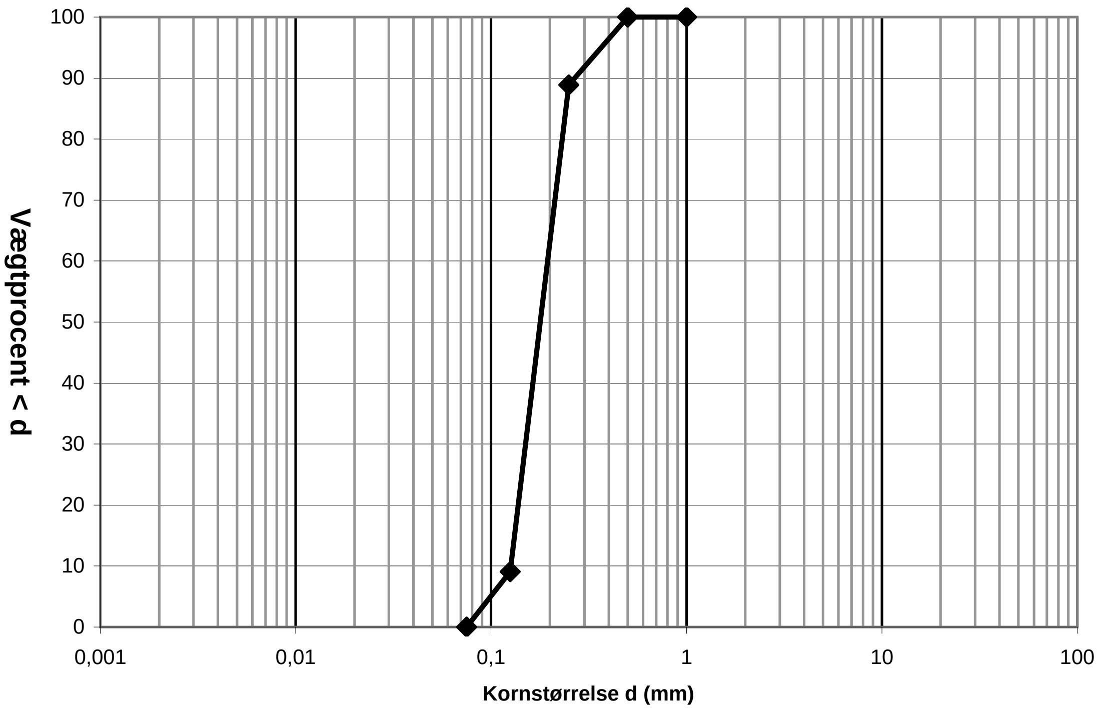
Test sheet test for : Sieve analysis

Sieve analysis 3

Bowl	[g]	219,1
Bowl + sand (prior to sieve analysis)	[g]	362,17
Sand	[g]	143,07

	Mesh size [mm]	Weight [g]	passing [g]	passing [%]
Sieve 1mm	1	0	143,03	100
Sieve 0.50 mm	0,5	0,02	143,01	100
Sieve 0.25 mm	0,25	15,86	127,15	89
Sieve 0.125 mm	0,125	114,18	12,97	9
Sieve 0.075 mm	0,075	12,82	0,15	0
Bottom sieve	0	0,15	0,00	0
Total		143,03		

Grain size:	d_{60} %	0,20
Non-uniform no.	$U=d_{60}$	1,6



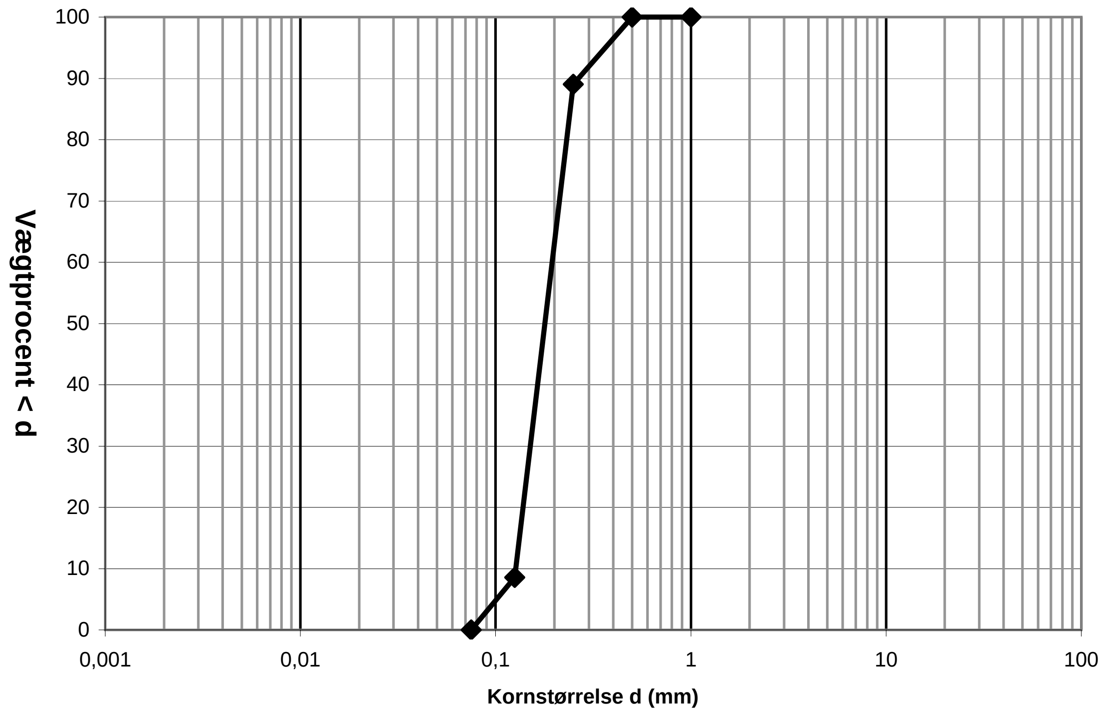
Test sheet test for : Sieve analysis

Sieve analysis 4

Bowl	[g]	224,64
Bowl + sand (prior to sieve analysis)	[g]	373,80
Sand	[g]	149,16

	Mesh size [mm]	Weight [g]	passing [g]	passing [%]
Sieve 1mm	1	0	149,01	100
Sieve 0.50 mm	0,5	0,01	149	100
Sieve 0.25 mm	0,25	16,34	132,66	89
Sieve 0.125 mm	0,125	119,86	12,8	9
Sieve 0.075 mm	0,075	12,66	0,14	0
Bottom sieve	0	0,14	0,00	0
Total		149,01		

Grain size:	d_{60} %	0,20
Non-uniform no.	U=d_{60}	1,6



Appendix E Pycnometer analyses on Fontainebleau sand.

Appendix with results from pycnometer analyses on Fontainebleau sand. Total of 1 page (excluding this).

Test sheet test for : Pycnometer analysis

Pycnometer test

			Bag no. 1		Bag no. 2	
Pycnometer number			1	2	3	4
Weight of pycnometer + dry specimen	m2	[g]	88,51	95,07	96,45	99,5
Weight of pycnometer + saturated specimen	m3	[g]	174,79	174,69	176,69	177,52
Calibration T=22.7 deg C	m1	[g]	149,2512	142,5404	145,2009	142,4565
Weight of pycnometer	m0	[g]	47,5271	43,4469	45,9414	43,2023
Volume of pycnometer	V	[cm^3]	101,7241	99,09347	99,2595	99,25417
Weight of sand	m4	[g]	40,98287	51,62307	50,5086	56,29767
Density of water from calibration	rhow1	[Mg/m^3]	0,997639	0,997639	0,997639	0,997639
Temperature of water		[degC]	22,7	22,7	22,7	22,7
Density of water from pycnometer test [	rhow2	[Mg/m^3]	0,997639	0,997639	0,997639	0,997639
Density of soil particles	rhos	[Mg/m^3]	2,647	2,645	2,649	2,645
Weighted				**2,646**		**2,6472**

Pycnometer test

			Bag no. 3		Bag no. 4	
Pycnometer number			5	6	14	15
Weight of pycnometer + dry specimen	m2	[g]	103,5024	100,7	101,291	102,3
Weight of pycnometer + saturated specimen	m3	[g]	182,46	181,16	183,02	182,78
Calibration T=22.7 deg C	m1	[g]	147,8537	149,0948	149,4475	148,7756
Weight of pycnometer	m0	[g]	47,9517	49,2338	47,3910	47,7188
Volume of pycnometer	V	[cm^3]	99,902	99,861	102,0565	101,0568
Weight of sand	m4	[g]	55,55	51,4662	53,9	54,5812
Density of water from calibration	rhow1	[Mg/m^3]	0,997639	0,997639	0,997639	0,997639
Temperature of water		[degC]	22,7	22,7	22,7	22,7
Density of water from pycnometer test [	rhow2	[Mg/m^3]	0,997639	0,997639	0,997639	0,997639
Density of soil particles	rhos	[Mg/m^3]	2,646	2,646	2,645	2,646
Weighted				**2,646**		**2,646**

Appendix F Void ratio analyses on Fontainebleau sand.

Appendix with results from void ratio analysis on Fontainebleau sand. Total of 3 pages (excluding this).

Test sheet test for : Void ratio analysis

Specimen no. 1 - loose

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,646026	2,646026	2,646026
Mass of cylinder	[g]	214	214	214
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,996	6,996	6,996
Test volume	[cm3]	69,7935	69,7935	69,7935
Mass of cylinder + sample	[g]	313,8	313,88	313,92
Mass of sample	[g]	99,8	99,88	99,92
Sample density, rd	[g/cm3]	1,4299	1,4311	1,4317
$e_{max} = \rho_s / \rho_s -1$		0,8505	0,84897	0,84823
Result: e_{max} = gns(e_{max_1}, e_{max_2},e_{max_3}) =		0,8492		

Specimen no. 1 - dense

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,646026	2,646026	2,646026
Mass of cylinder	[g]	214	214	214
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,766	6,456	6,686
Test volume	[cm3]	67,499	64,406	66,7009
Mass of cylinder + sample	[g]	330,41	324,88	328,96
Mass of sample	[g]	116,41	110,88	114,96
Sample density, rd	[g/cm3]	1,7246	1,7216	1,7235
$e_{min} = \rho_s / \rho_s -1$		0,53427	0,53699	0,53525
Resultat: e_{min} = gns(e_{min_1}, e_{min_2}) =		0,5356		

Specimen no. 2 - loose

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,647185	2,647185	2,647185
Mass of cylinder	[g]	214	214	214
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,996	6,996	6,996
Test volume	[cm3]	69,7935	69,7935	69,7935
Mass of cylinder + sample	[g]	313,79	313,59	313,6
Mass of sample	[g]	99,79	99,59	99,6
Sample density, rd	[g/cm3]	1,4298	1,4269	1,4271
$e_{max} = \rho_s / \rho_s -1$		0,8515	0,8552	0,8550
Resultat: e_{max} = gns(e_{max_1}, e_{max_2},e_{max_3}) =		0,8539		

Specimen no. 2 - dense

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,647185	2,647185	2,647185
Mass of cylinder	[g]	214	214	214
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,616	6,676	6,666
Test volume	[cm3]	66,003	66,601	66,5014
Mass of cylinder + sample	[g]	327,14	328,58	328,25
Mass of sample	[g]	113,14	114,58	114,25
Sample density, rd	[g/cm3]	1,7142	1,7204	1,7180
$e_{min} = \rho_s / \rho_s -1$		0,5443	0,5387	0,5408
Resultat: e_{min} = gns(e_{min_1}, e_{min_2}) =		0,5415		

Test sheet test for : Void ratio analysis

Specimen no. 3 - loose

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,646497	2,646497	2,646497
Mass of cylinder	[g]	215,18	215,18	215,18
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,993	6,993	6,993
Test volume	[cm3]	69,7636	69,7636	69,7636
Mass of cylinder + sample	[g]	314,14	314,19	314,18
Mass of sample	[g]	98,96	99,01	99
Sample density, rd	[g/cm3]	1,4185	1,4192	1,4191
$e_{max} = \rho_s / \rho_s -1$		0,8657	0,8648	0,8649
Resultat: e_{max} = gns(e_{max_1}, e_{max_2},e_{max_3}) =		0,8651		

Specimen no. 3 - dense

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,646497	2,646497	2,646497
Mass of cylinder	[g]	215,18	215,18	215,18
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,152	6,514	6,533
Test volume	[cm3]	61,374	64,985	65,1745
Mass of cylinder + sample	[g]	319,61	325,75	325,78
Mass of sample	[g]	104,43	110,57	110,6
Sample density, rd	[g/cm3]	1,7015	1,7015	1,6970
$e_{min} = \rho_s / \rho_s -1$		0,5553	0,5554	0,5595
Resultat: e_{min} = gns(e_{min_1}, e_{min_2}) =		0,5554		

Specimen no. 4 - loose

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,646297	2,646297	2,646297
Mass of cylinder	[g]	215,18	215,18	215,18
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,993	6,993	6,993
Test volume	[cm3]	69,7636	69,7636	69,7636
Mass of cylinder + sample	[g]	314,1	314,02	314,25
Mass of sample	[g]	98,92	98,84	99,07
Sample density, rd	[g/cm3]	1,4179	1,4168	1,4201
$e_{max} = \rho_s / \rho_s -1$		0,866	0,868	0,863
Resultat: e_{max} = gns(e_{max_1}, e_{max_2},e_{max_3}) =		0,8659		

Specimen no. 4 - dense

Test material		Test 1	Test 2	Test 3
Grain density, ρ_s	[g/cm3]	2,646297	2,646297	2,646297
Mass of cylinder	[g]	215,18	215,18	215,18
Diameter of cylinder	[cm]	3,564	3,564	3,564
Heigth of cylinder	[cm]	6,703	6,433	6,393
Test volume	[cm3]	66,870	64,177	63,7779
Mass of cylinder + sample	[g]	328,33	324,24	323,79
Mass of sample	[g]	113,15	109,06	108,61
Sample density, rd	[g/cm3]	1,6921	1,6994	1,7029
$e_{min} = \rho_s / \rho_s -1$		0,56393	0,55723	0,5540
Resultat: e_{min} = gns(e_{min_1}, e_{min_2}) =		0,5606		

Conclusion

e_{max}	0,849	0,854	0,865	0,866
e_{min}	0,536	0,542	0,555	0,561
Average e_{max}				0,859
Average e_{min}				0,548

Appendix G Triaxial tests on Fontainebleau sand.

Appendix with results from triaxial tests on Fontainebleau sand. Total of 6 pages (excluding this).

CD triaxial test on dry sand, 30 kPa cell pressure

Project:

Numerical and physical modelling of laterally loaded pile in sand subject to cyclic loading

Description of sample: Bag sample of Fontainebleau sand applied in centrifuge tests. Sample taken after centrifuge tests.

Laboratory assistant: Rasmus Klinkvort

Date: 02-02-2010

Grain density:

ds	2,646

Minimum void ratio:

emin	0,548

Maximum void ratio:

emax	0,859

Sample void ratio:

e	0,599

Sample relative density:

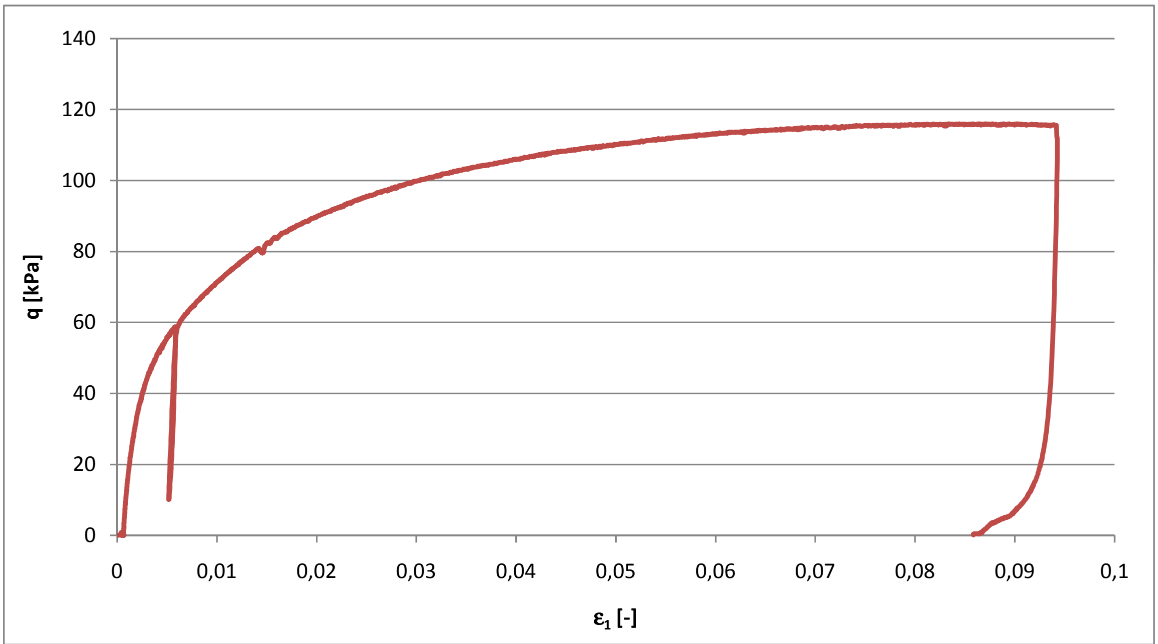
Id	0,837

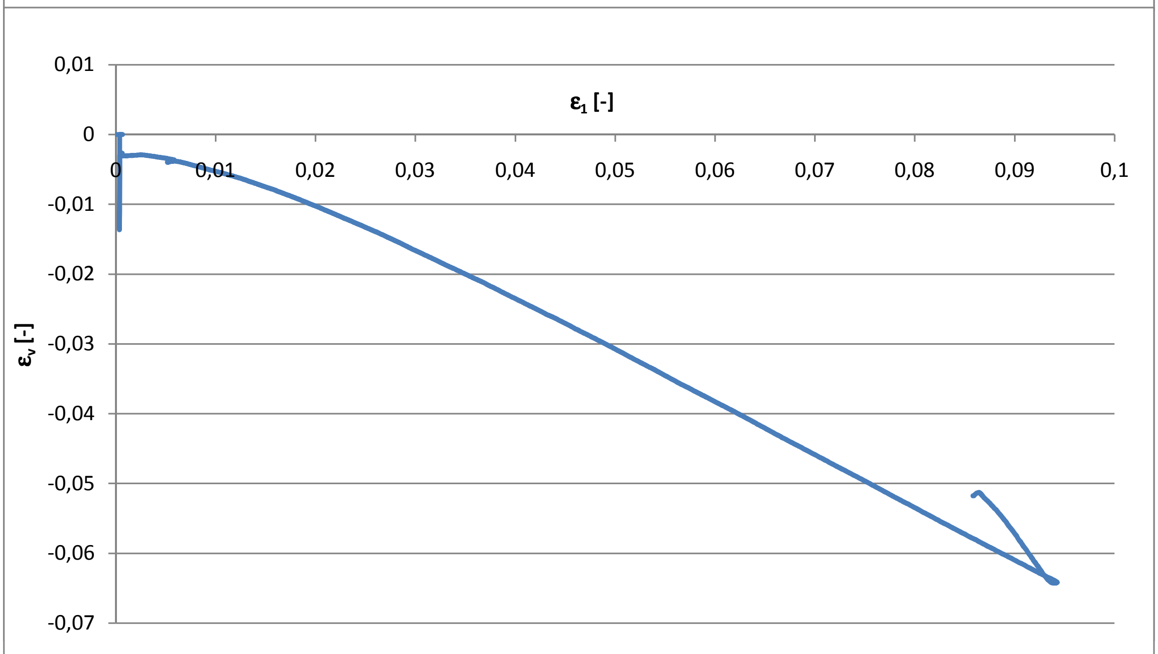
Sample dimensions:

Height, H:	7
Diameter, D:	7

Sample density:

ρ	1,665 g/cm3





CD triaxial test on dry sand, 60 kPa cell pressure

Project:
Numerical and physical modelling of laterally loaded pile in sand subject to cyclic loading

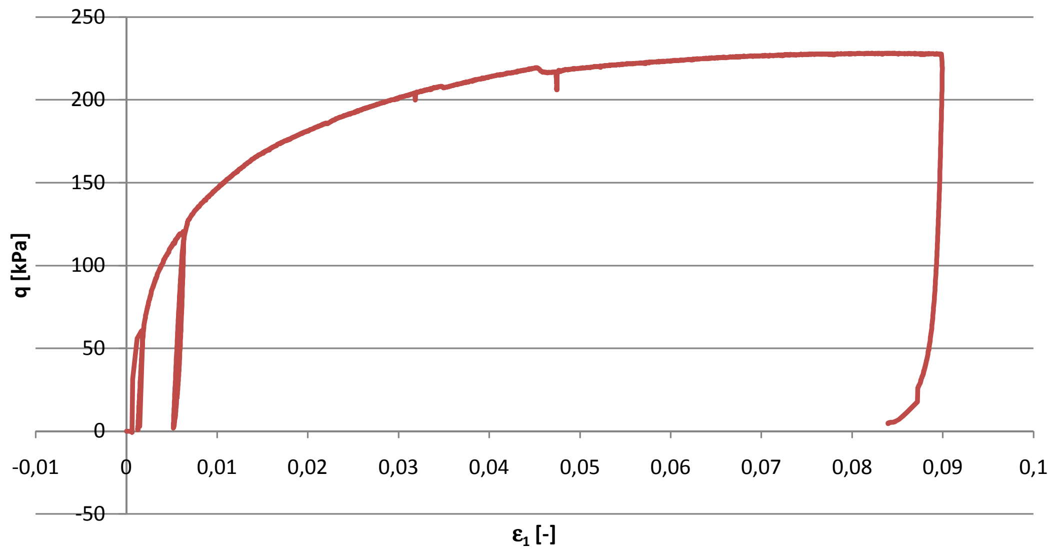
Description of sample: Bag sample of Fontainebleau sand applied in centrifuge tests. Sample taken after centrifuge tests.

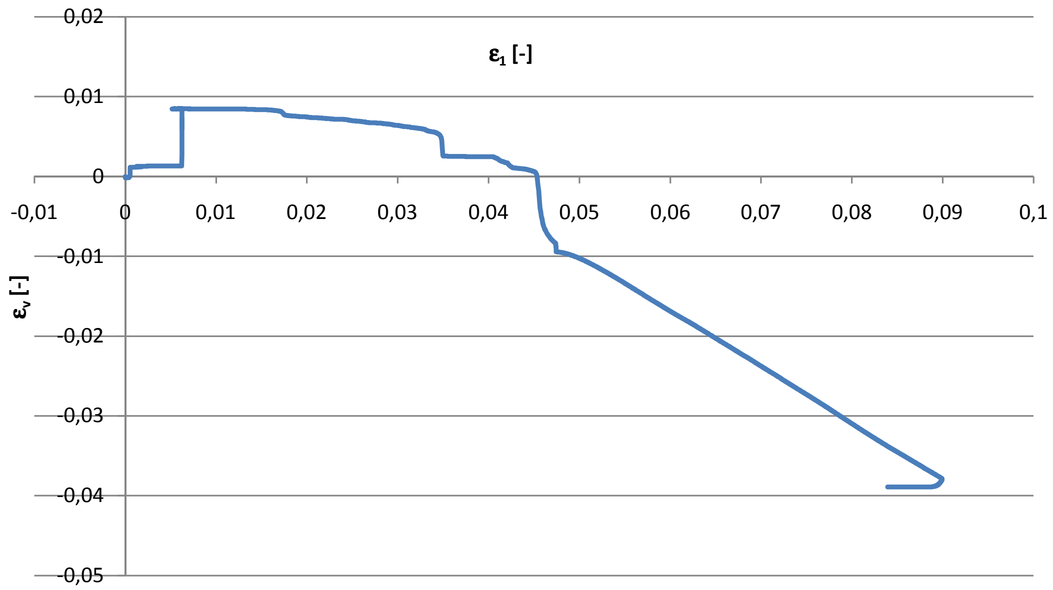
Laboratory assistant:
Rasmus Klinkvort

Date:
28-01-2010

Grain density:
ds 2,646
Minimum void ratio:
emin 0,548
Maximum void ratio:
emax 0,859

Sample void ratio:
e 0,599
Sample relative density:
Id 0,837
Sample dimensions:
Height, H: 7
Diameter, D: 7
Sample density:
ρ 1,665 g/cm3





CD triaxial test on dry sand, 150 kPa cell pressure

Project:

Numerical and physical modelling of laterally loaded pile in sand subject to cyclic loading

Description of sample: Bag sample of Fontainebleau sand applied in centrifuge tests. Sample taken after centrifuge tests.

Laboratory assistant: Rasmus Klinkvort

Date: 04-02-2010

Grain density:

ds	2,646

Minimum void ratio:

emin	0,548

Maximum void ratio:

emax	0,859

Sample void ratio:

e	0,599

Sample relative density:

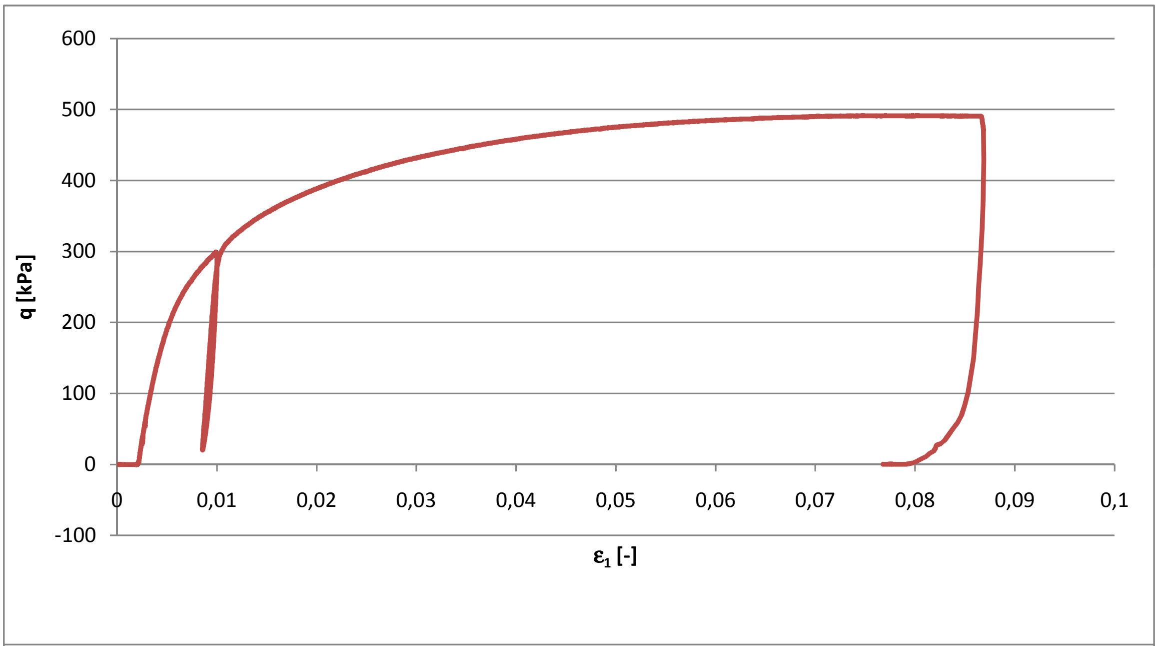
Id	0,837

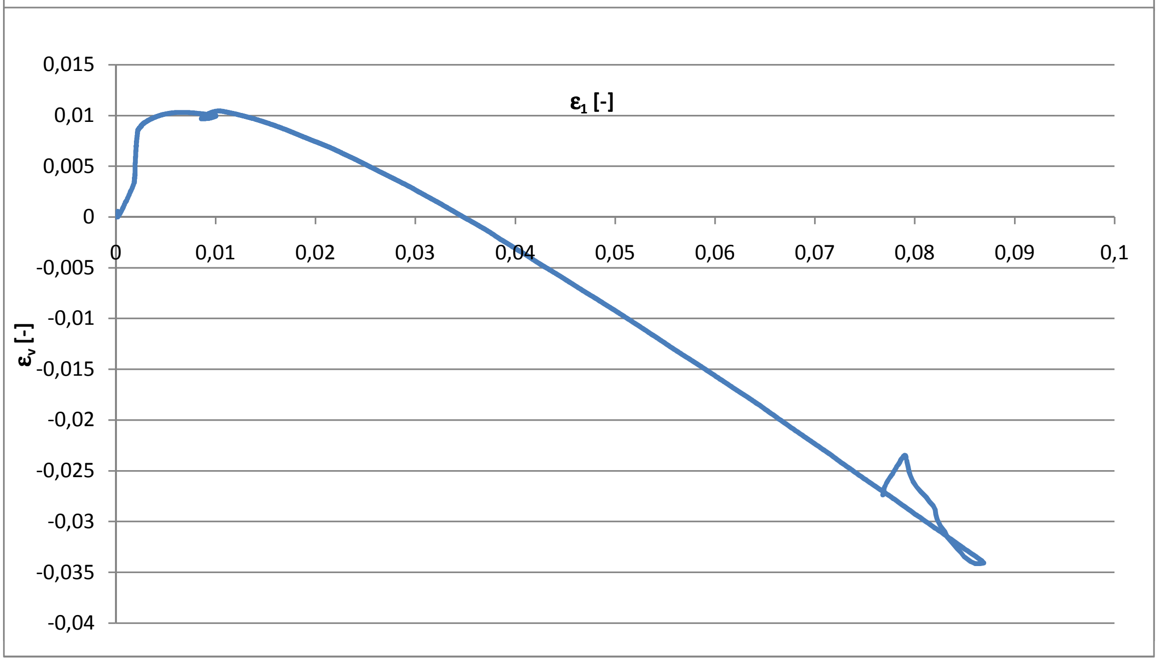
Sample dimensions:

Height, H:	7
Diameter, D:	7

Sample density:

ρ	1,665 g/cm3





CD triaxial test on dry sand, 150 kPa cell pressure

Project:

Numerical and physical modelling of laterally loaded pile in sand subject to cyclic loading

Description of sample: Bag sample of Fontainebleau sand applied in centrifuge tests. Sample taken after centrifuge tests.

Laboratory assistant: Rasmus Klinkvort

Date: 03-03-2010

Grain density:

ds	2,646

Minimum void ratio:

emin	0,548

Maximum void ratio:

emax	0,859

Sample void ratio:

e	0,599

Sample relative density:

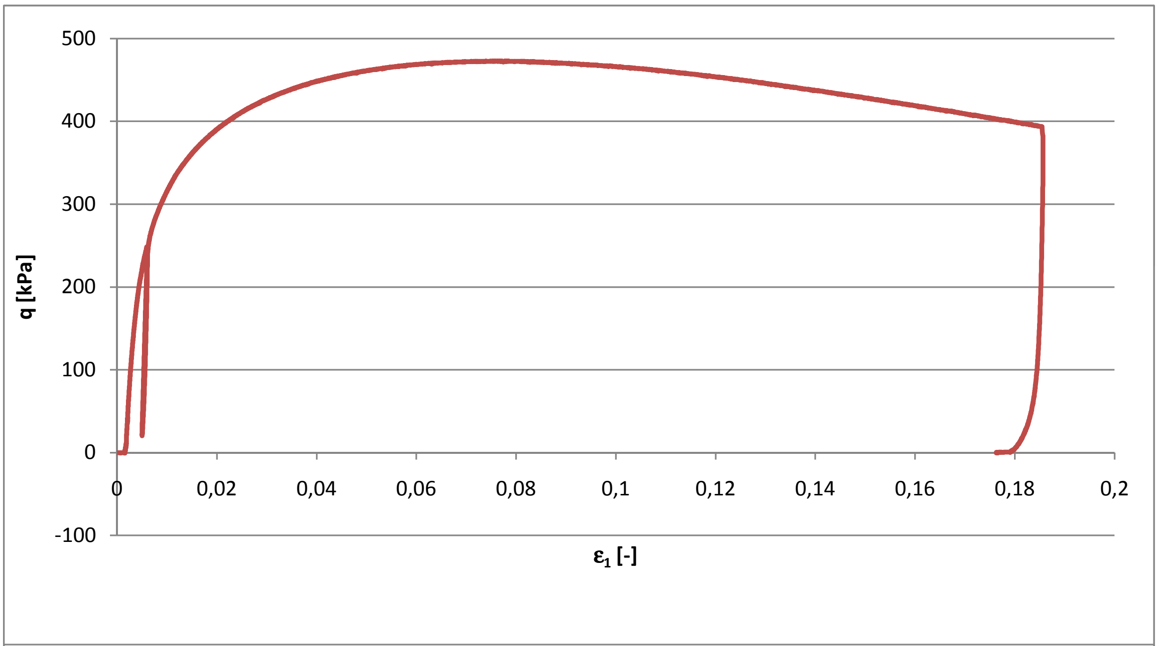
Id	0,837

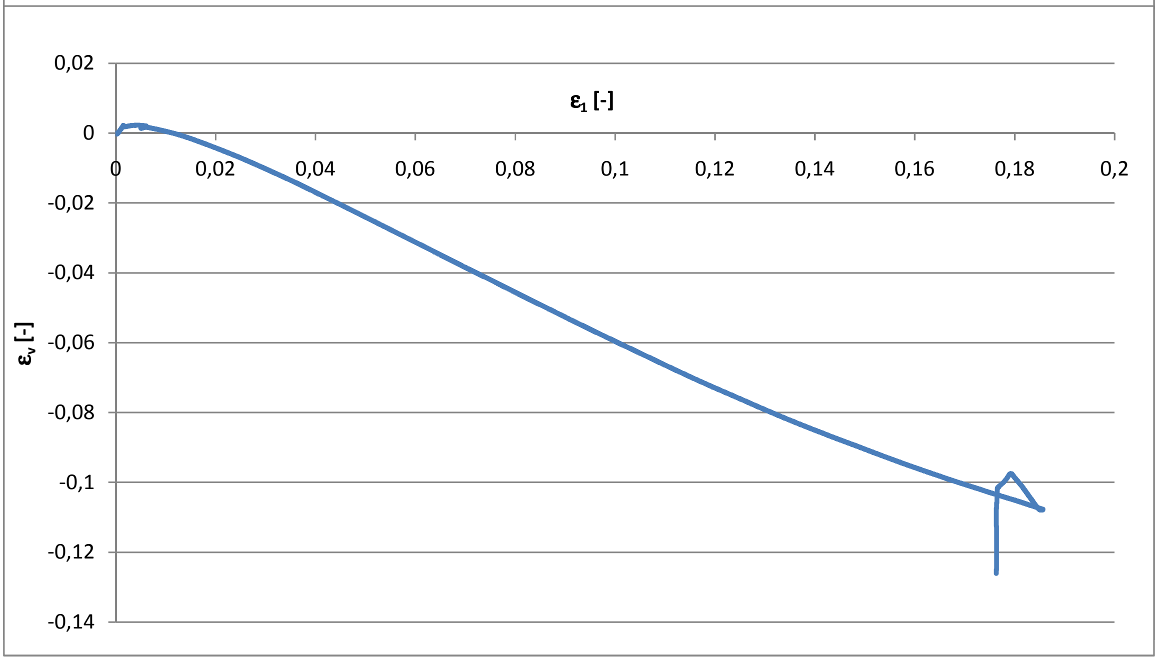
Sample dimensions:

Height, H:	7
Diameter, D:	7

Sample density:

ρ	1,665	g/cm3





CD triaxial test on dry sand, 300 kPa cell pressure

Project:
Numerical and physical modelling of laterally loaded pile in sand subject to cyclic loading

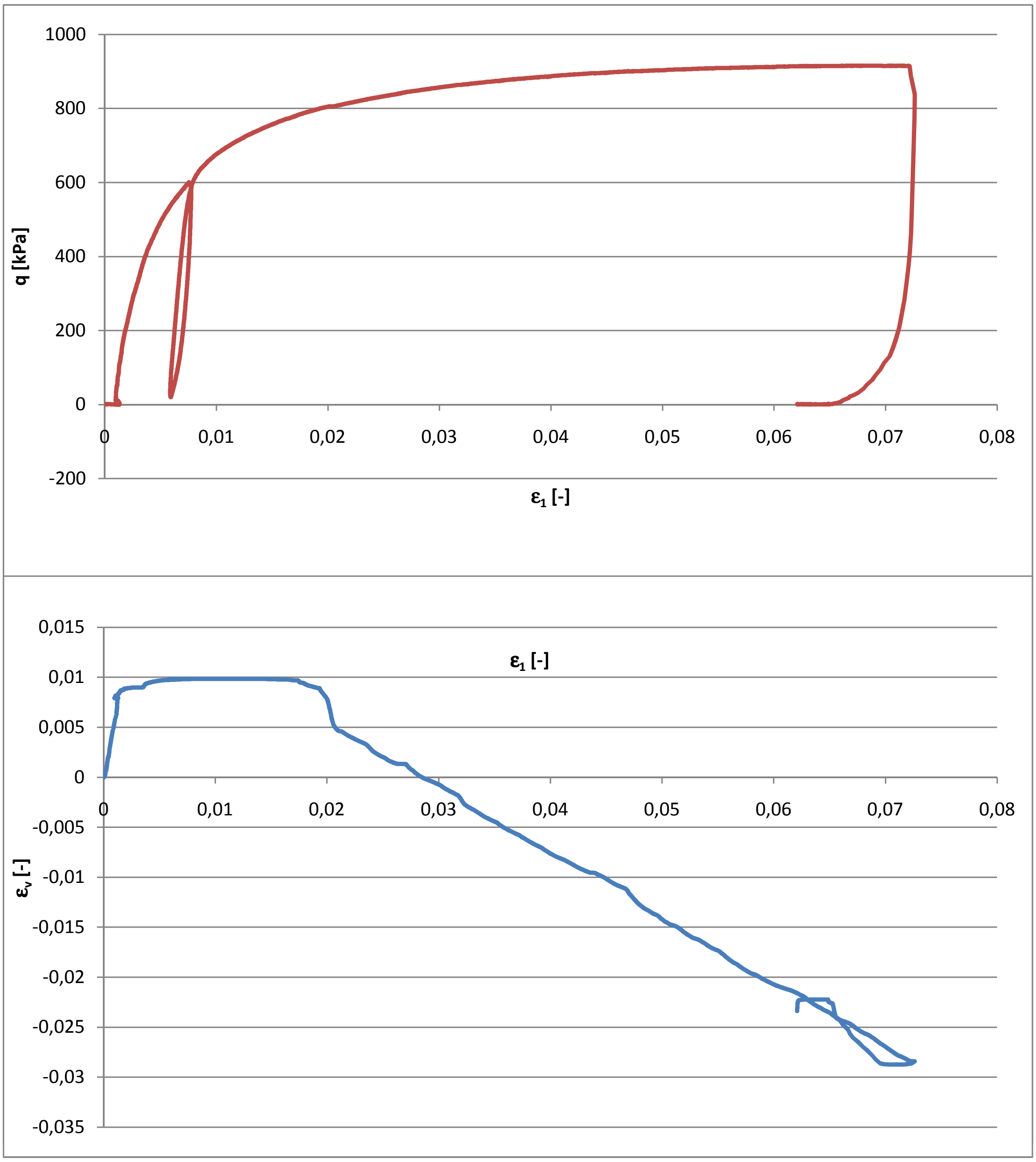
Description of sample: Bag sample of Fontainebleau sand applied in centrifuge tests. Sample taken after centrifuge tests.

Laboratory assistant:
Rasmus Klinkvort

Date:
05-02-2010

Grain density:
ds 2,646
Minimum void ratio:
emin 0,548
Maximum void ratio:
emax 0,859

Sample void ratio:
e 0,599
Sample relative density:
Id 0,837
Sample dimensions:
Height, H: 7
Diameter, D: 7
Sample density:
ρ 1,665 g/cm3



CD triaxial test on dry sand, 300 kPa cell pressure

Project:

Numerical and physical modelling of laterally loaded pile in sand subject to cyclic loading

Description of sample: Bag sample of Fontainebleau sand applied in centrifuge tests. Sample taken after centrifuge tests.

Laboratory assistant:

Rasmus Klinkvort

Date:

18-02-2010

Grain density:

ds	2,646

Minimum void ratio:

emin	0,548

Maximum void ratio:

emax	0,859

Sample void ratio:

e	0,599

Sample relative density:

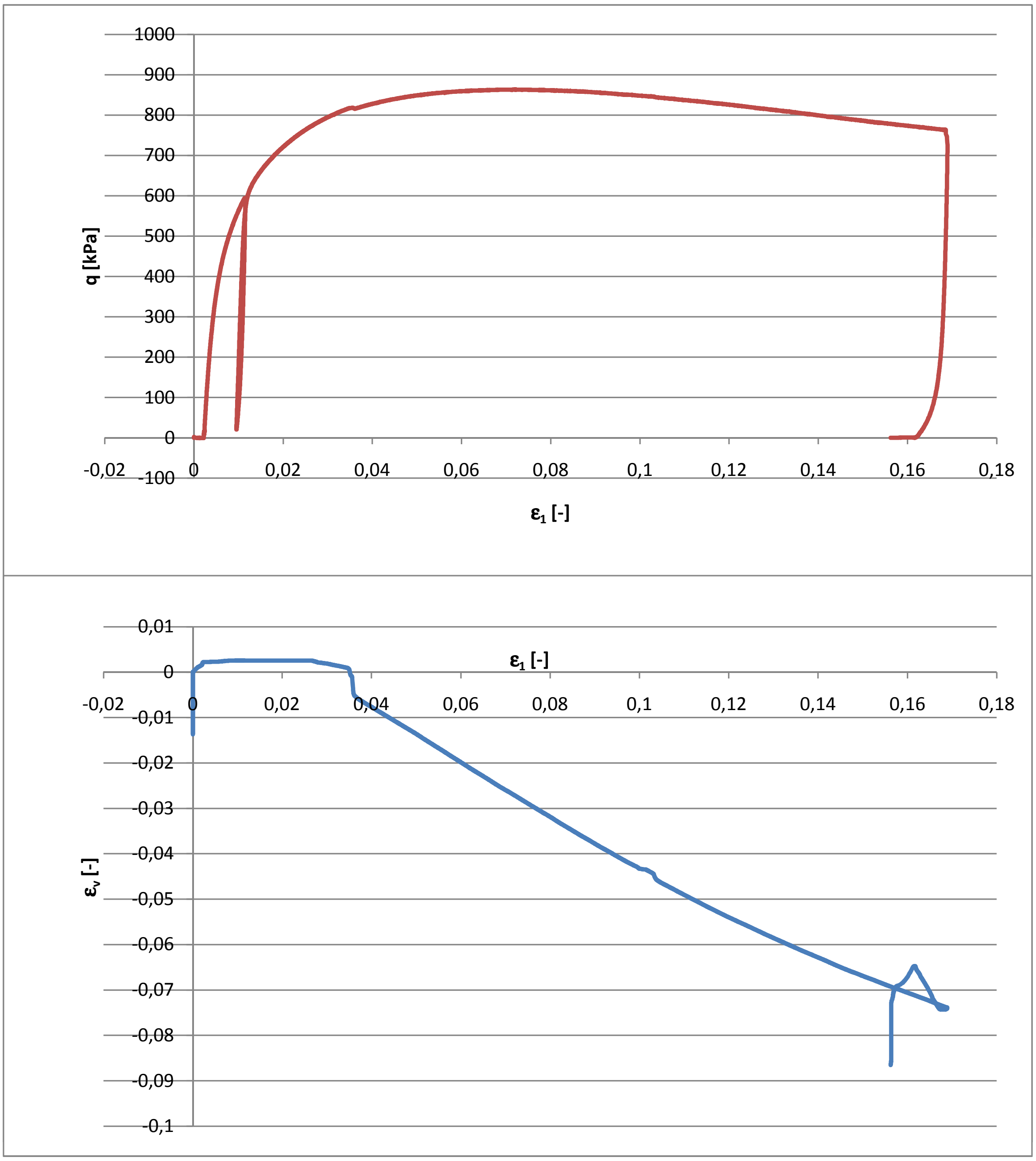
Id	0,837

Sample dimensions:

Height, H:	7
Diameter, D:	7

Sample density:

ρ	1,665	g/cm3



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