Deltares

Field test Rapid load Testing Waddinxveen

Factual report

dr.ir. P. Holscher

Deltares

Title
Field test Rapid load Testing Waddinxveen

Project	Reference	Pages
1001055-014	1001055-014-GEO-0001	95

Trefwoorden
Field test, static load test, rapid load test, bearing capacity, stiffness, strain measurements, pore water pressures.

Samenvatting
Two piles are driven and testes. Pile 1 is loaded rapidly and statically, Pile 2 the other way around. During the tests, the standard measurements at the pile head are carried out. Additionally, strains in the pile are measured at three levels and the excess pore water pressures close to the piles are measured. This report describes the field test and presents the measured data.

Referenties
Delft Cluster werkpakket “Snelle paaltesten” in het project “Nieuw perspectief voor funderingen en bouwputten; DC-CUR commissie H410 “Snelle paaltesten”.

Versie	Datum	Auteur	Paraaf	Review	Paraaf	Goedkeuring	Paraaf
01	mrt 2009	dr.ir. P. Holscher		prof.ir. A.F. van Tol		ing. M. Hutteman	
02	dec 2009	dr.ir. P. Holscher		prof.ir. A.F. van Tol		ing. M. Hutteman	

State
final

Contents

Bijlage(n)

List of Tables

List of Figures

List of Photographs

1 Introduction

1.1 Goal of this test

Within the framework of the Delft Cluster work package Rapid Load testing the CUR-commission H410 carried out a field test on two concrete piles at Waddinxveen.

The tests have two goals:

- Validation of the interpretation method for rapid load testing.
- Validation for the modelling of the pore water pressure development during a rapid load test.

Two prefabricated instrumented piles are tested statically and rapidly. The test field is located behind the IFCO building at Waddinxveen. Besides the standard measurements of force, displacement and acceleration on the pile head, also the strains at several levels in the pile and the pore water pressures under the pile toe en near the pile toe have been measured.

1.2 Project team

The test is cooperation between several partners in the project Table 1.1 shows the partners and their tasks.

Partner	Tasks
Betonson BV	• Production of piles • Pile installation (driving)
Deltares	• Project management • Instrumentation of the piles • Strain measurements • High rate sampling strain and pore water pressures • Delivery pore water pressure transducer at depth
GWR	• Standard static test measurement • Low rate sampling strain
Fundex Verstreaten	• Static test equipment
IFCO Profound	• Statnamic test equipment • Standard measurement Statnamic test • Delivery pore water pressure dives pile toe
Ballast Nedam	• Dynamic testing measurement
Vroom	• Dynamic load test equipment • Redrive for saving piles (further use)

Table 1.1 Participants and their primary tasks within the field test

A plan for execution had been made [Deltares, 2008].

1.3 Location of the test

The test location is situated at the parking behind the IFCO-office, Limaweg 17 at Waddinxveen.
The Dutch triangular coordinates are:

- Pile 1 (x=104102.52, y=450371.93).
- Pile 2 (x=104096.69, y=450369.81).

Note: x-coordinate is in east direction
y-coordinate is in north direction.

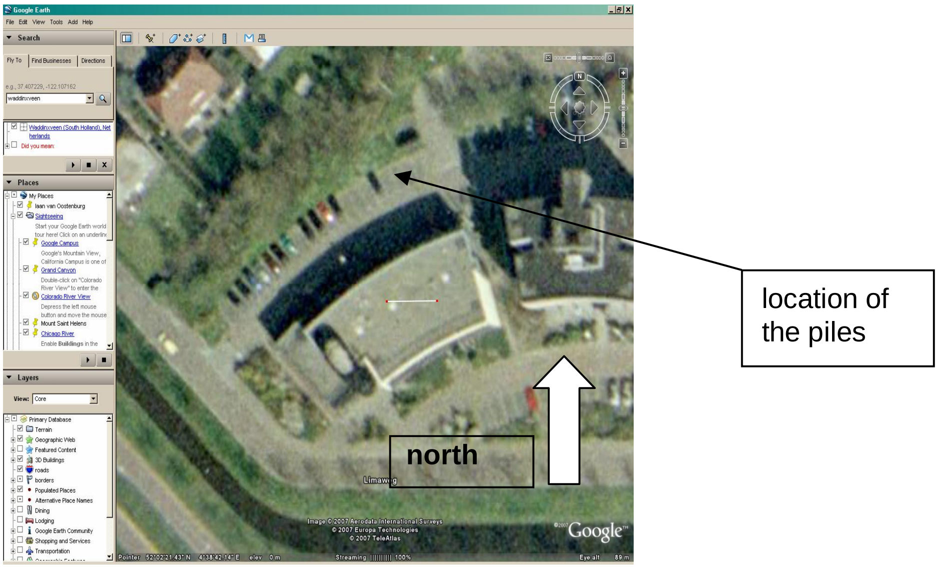


Photo 1.1 Aerial view of test location (from google Earth)

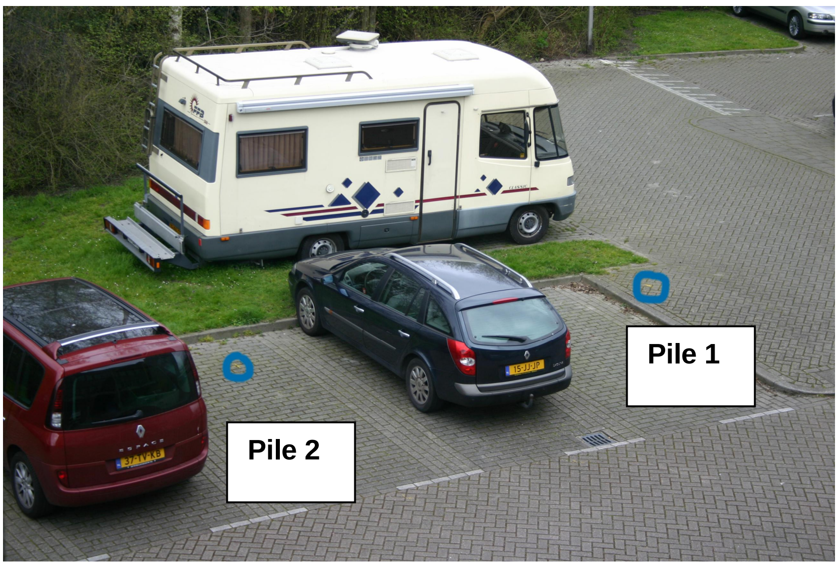


Photo 1.2 Location of test piles details (photo profound)

2 Results field survey

2.1 Measurements

The soil profile exists of (from top to bottom):

- 1 m thick sandfill.
- 4 m clay.
- 2 m clay.
- more than 12 m sand.

At exactly the locations of each pile, a CPT was carried out. The results are shown in Appendix B.

2.2 Interpretation

Based on the cpt's, the soil layering for the two locations can be made, see Table 2.1 and Table 2.2.

Number	Upperside Layer	unit weight dry	unit weight saturated	Angle of internal friction	soil type
	[m NAP]	[kN/m3]	[kN/m3]	[deg]	
1	-5,10	17	19	35	sand
2	-6,2	15	17	25	clay
3	-10,0	11	11	15	peat
4	-12,0	18	20	32,5	sand
	-25,0	end of CPT			

Table 2.1 Interpretation CPT 1 (van Dijk, 2007)

Number	Upperside Layer	unit weight dry	unit weight saturated	Angle of internal friction	soil type
	[m NAP]	[kN/m3]	[kN/m3]	[deg]	
1	-5,10	17	19	35	sand
2	-6,4	15	17	25	clay
3	-9,7	11	11	15	peat
4	-12,0	18	20	32,5	sand
	-21,0	end of CPT			

Table 2.2 Interpretation CPT 2 (van Dijk, 2007)

Based on these cpt's, the bearing capacity of pile 1 is estimated on 1225 kN and of pile 2 on 1190 kN.

3 Piles

3.1 Design

The piles are a standard designed prefabricated pile Appendix C shows the detailed design with the measurement equipment.

3.2 Production

The piles are poured at 14 April 2008.

Table 3.1 and Table 3.2 show the position of the transducers in the piles. Graphical details are found in Appendix C and Figure 3.3.

Level	Depth from head [m]	Transducer top	Transducer bottom
Pile head	0.5	19	18
Top sand layer	9.1	30	27
Pile toe	10.0	29	26

Table 3.1 Position of strain transducers in pile 1

Level	Depth from head [m]	Transducer top	Transducer bottom
Pile head	0.5	30	21
Top sand layer	9.1	31	28
Pile toe	10.0	32	26

Table 3.2 Position of strain transducers in pile 2

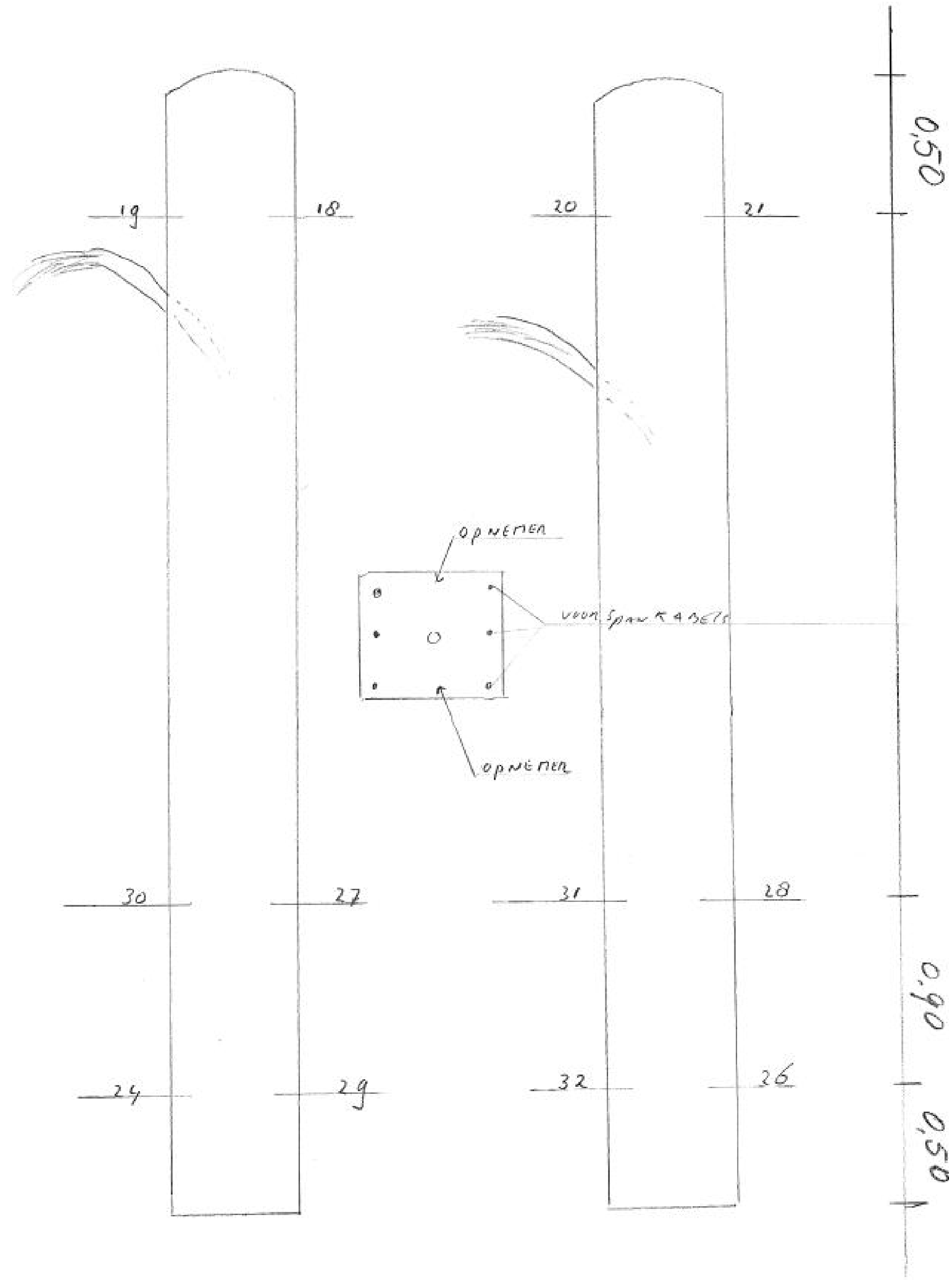


Figure 3.1 *Position of the strain transducers*

Photo 3.1 Strain bar and reinforcement of the pile

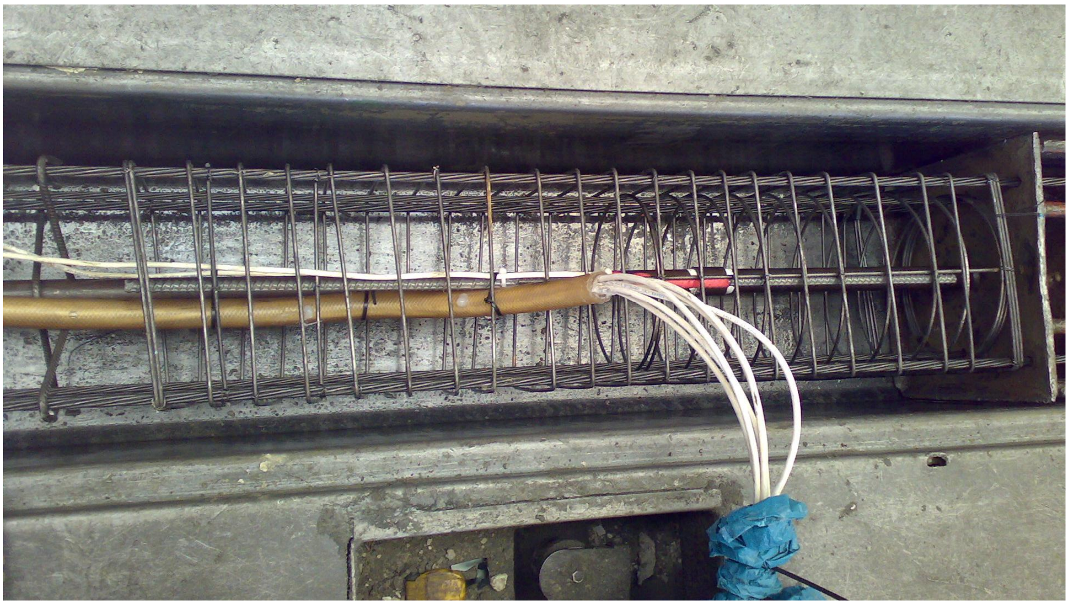


Photo 3.2 Detail of strain bar and cable connection

3.3 Installation

The piles were driven by Betonson at 17-05-2008. No further specifications are available.

3.4 Residual stresses

The strains in the strain gauges are measured before and after pile driving [Brassinga, 2008]. The differential strains are calculated. This results in the strains due to pile driving, since the pile is assumed to have no normal force in longitudinal direction, the measured strains are due to e.g. pre-stress and curing of the concrete.
Table 3.3 and Table 3.4 show the results of this measurement

Level	Transducer	Strain	Transducer	Strain
Pile head	19	34	18	15
Start sand layer	30	24	27	-8
Pile toe	24	-9	29	-13

Table 3.3 Measured strains (μm/m) due to pile driving, pile 1

Level	Transducer	Strain	Transducer	Strain
Pile head	20	37	21	17
Start sand layer	31	-1	28	-40
Pile toe	32	33	26	-27

Table 3.4 Measured strains (μm/m) due to pile driving, pile 2

It turns out that the strains are not very consistent. Noting that 1 μm/m means 4 to 5 kN forces in the order of 10% of the bearing capacity are seen, but due to the large differences in one cross section, also bending moments are observed.

3.5 Pore water pressure transducers

At the pile toe, a pore water transducer is installed, just in the middle of the pile toe. During pile production a 32.8 mm external diameter pipe (25.4 mm (1'') internal diameter) are placed in each pile before pouring the concrete. Just for pile driving, a BAT-filter tip is placed at the pile toe. During rapid load testing, the measurement device is placed in the filter tip of the pile tested.

Details of the pore water pressure device at the pile tip are shown in Section 4.3 of [Deltares, 2008].

The day before the RLT on pile 2, a piezo-electric pore water pressure transducer is installed. Installation took place by pushing it into the soil (like a CPT device). The weight of the Statnamic device was used as counter weight.

The position of this transducer was:

- Distance to the pile 0.30 m
- Depth 15.30 m NAP (this is 0.05 m above the toe level).

It is noted that installation of such a device at this depth has quite limited accuracy, so the horizontal distance to the pile might be larger than the distance mentioned above. It is expected that distance between the pile toe and the transducer is larger than 0.30 m.

4 Predictions

Before the pile driving, some members of commission CUR H410 (here called “predictors”) predicted the stiffness, the bearing capacity and the dynamic behaviour of the piles. This chapter treats the results.

4.1 Prediction contest

4.1.1 Information and question

The following information was provided to the predictors:

“*Two field tests on prefabricated concrete piles will be carried out at Waddinxveen, the Netherlands. These piles will be driven into the sand layer. Both piles are tested by a static load test and a rapid load test (4 MN Statnamic device). The order of the tests will differ for the two piles: Pile number S01 (located at CPT S01) will be tested first statically and rapidly afterwards; pile number S02 (located at CPT S02) will be tested first rapidly and statically afterwards. The full details of the piles and the CPT’s are shown in the appendix.*

We like to have insight in the (by experts) expected behaviour of these piles.
Therefore, we would like to have your answer on the following questions for both piles:

1. *What is the settlement of the pile head under the second static load step of 180 kN (total load is 360 kN) on the pile head`.*
2. *What is the settlement of the pile head under the third static load step of 180 kN (total load is then 540 kN) on the pile head.*
3. *Which static load on the pile head is required to obtain a pile head displacement of 395 mm (this is 10% of the equivalent diameter).*
4. *Which Statnamic load on the pile head is required to obtain a pile head displacement of 395 mm (this is 10% of the equivalent diameter.)*

[......]

Please note that the static load test and the rapid load test are considered as two independent experiments. Therefore, the level of the pile head at the start of each test is assumed zero.”

[end of citation]

The cpt’s are added to this report in Appendix B.

4.1.2 Results of the predictions

Table 4.1 and Table 4.2 present the results of the predictions. A question mark “?” means that the predictor did not answer this question.

Pile number	Pile S01				
	Predictors				
Question	A	B	C	D	E
1. Displacement at 360kN static load	2,8 mm	3,95 mm	1,6 mm	2,4 mm	1,5 mm
2. Displacement at 540kN static load	4,5 mm	11,85 mm	3,2 mm	3,6 mm	2,0 mm
3. Static load at 10% D displacement	1406 kN	780 kN	1175 kN	1410 kN	1350 kN
4. Statnamic load required for 10% D displacement	* kN	* kN	1400 kN	2450 kN	1700 kN

Table 4.1 Predictions for pile 1 based on CPT 1
**: not provided*

Pile number	Pile S02				
	Predictors				
Question	A	B	C	D	E
1. Displacement at 360kN static load	4,5 mm	3,16 mm	1,6 mm	2,4 mm	1,5 mm
2. Displacement at 540kN static load	5,5 mm	13,8 mm	3,2 mm	3,6 mm	2,0 mm
3. Static load at 10% D displacement	1253 kN	720 kN	1175 kN	1410 kN	1350 kN
4. Statnamic load required for 10% D displacement	* kN	* kN	1400 kN	2450 kN	1700 kN

Table 4.2 Predictions for pile 2 based on CPT 2
**: not provided*

4.2 MFoundation calculations

After doing the tests, the results are interpreted within the Delft Cluster project “Axially loaded piles”. A standard MFoundation solution is part of this interpretation. This Section presents the results of this calculation. It is noted that these calculations are no prediction, since they are done after the measurements Table 4.3 presents the results.

CPT	Toe level [m NAP]	Ground level [m NAP]	$F_{r;max;tip}$ [kN]	$F_{r;max;shaft}$ [kN]	$F_{r;max}$ [kN]
S01	-15.35	-5.07	851	479	1340
S02	-15.35	-5.13	850	468	1318

Table 4.3 Result of Mfoundation calculation in project “Axially loaded piles”

5 Static load tests

5.1 Execution SLT (Maintained load test)

Loading schedule

De static load test was executed in according tot NEN 6745. The Prediction of the ultimate bearing capacity gave as a result a bearing capacity between 1350 and 1400 kN. In order to be able to reach an accurate approach of the bearing capacity the test was carried out in loading steps of 175 kN, so it was expected that at least 8 steps would be necessary to reach the ultimate load.

Measurements

Load

The load was applied by means of a hydraulic jack. The load was transferred to a calibrated load cell. The capacity of the load cell was 3000 kN. The reading of the force was made visible on a display and stored on a data acquisition system.
The accuracy of the readings was 1 kN.

Deformations

To measure the vertical deformation of the pile head three rulers were applied near the top of the pile. Two of them were applied at opposite sides of the pile; the third ruler was applied in a perpendicular direction. The readings were carried out with the help of a Leica precision level instrument and were taken manually. The level instrument was placed at a distance of about 10 m from the pile. The accuracy of the readings of the level instrument was 0.1 mm
The reading were taken from the moment directly after the application of the intended loading step en at time steps of 2, 4, 7, 10, 15, 20, 30, 40 and 60 minutes
Besides the vertical deformation of the pile head was measured with the electro-optical displacement device of IFCO.

Strain gauges

During the load tests, the strain gauges were measured continuous. The measuring signals were recorded through a data logger on a hard disk recorder. For the calculation of the forces from the measuring signals the following factors were used (as determined by Deltares)

- E_{eq} (concrete+steel) = 38237 MPa
- A_{eq} (concrete+steel) = 121250 mm^2

The axial stiffness of the pile is taken as:

- EA_{eq} = 4.636E9 kN

5.2 Test pile 2

The first loading test was executed on pile nr 2 on Tuesday June 17, 2008.
This was a virgin pile; it was not yet loaded by a Statnamic test.

5.2.1 Results of standard measurements

The deformation readings were set to zero under a load of 10 kN on the pile head. The load versus time during the test is given in Figure 5.1. On the vertical axis, the time is shown, while the horizontal axis shows the load.

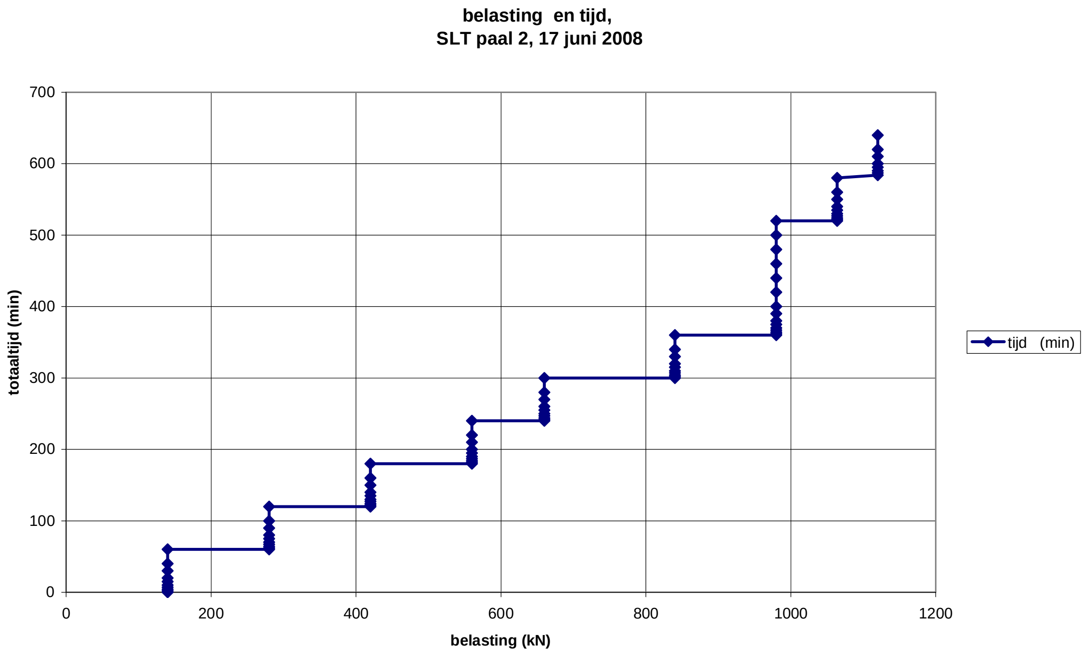


Figure 5.1 *Relation between the load and time, test pile 2.*

In Figure 5.2 the relation between the pile head displacement on time is given. The displacement is calculated as the mean value of the 3 measured levels.

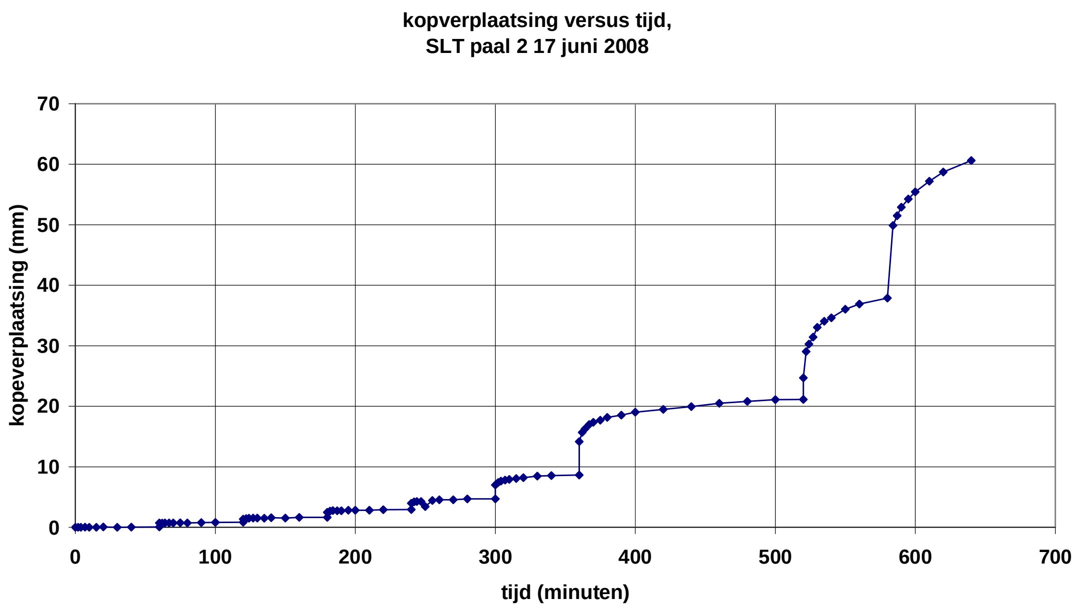


Figure 5.2 *Relation between the pile head displacements and time, test pile 2*

In Figure 5.3, the relation between the force at the pile head and the deformation of the pile head is shown. The force is determined from the load cell readings.

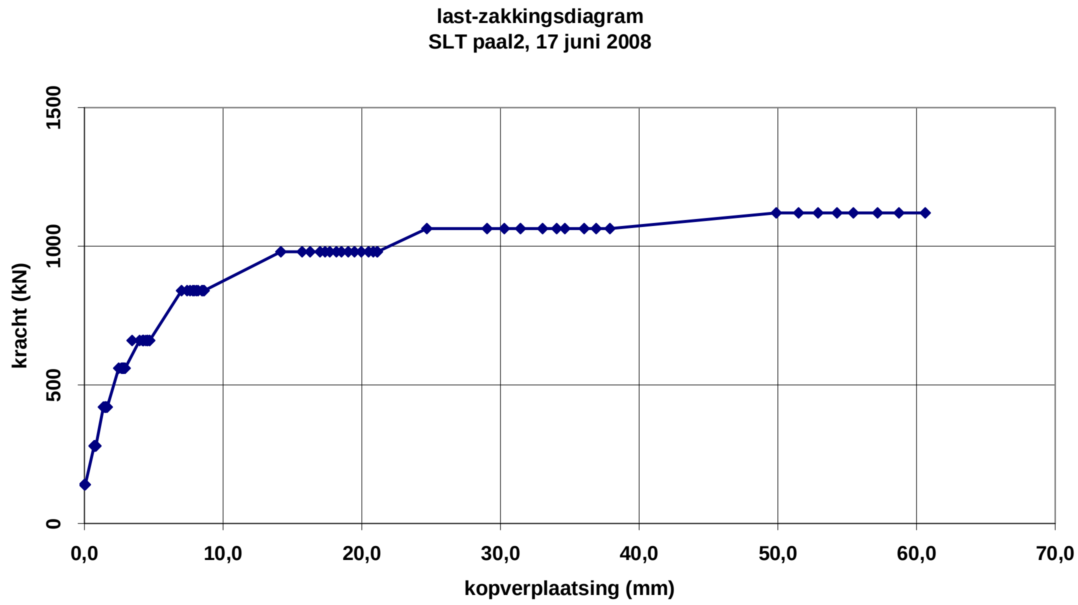


Figure 5.3 Relation between force and pile head displacement

Force in the pile head

After the test was completed, it was concluded that during the adjustment of the readings a mistake had occurred in the measuring of the force on the pile head. It turned out that the readings were too high with a constant factor 1.25. Therefore, the load steps applied had a level of 140 instead of 175 as planned. The results given in the Figures 5.1 to 5.3 are corrected for this.

After completion of both static pile tests the load cell and the data logger heave been calibrated in the test facility of Public Works Rotterdam. It turned out that the corrected tuning of the equipment was necessary.

During the subsequent stages of the test, the minimal loading time was 1 hour. If the creep was larger than 1 mm, the step was elongated until the creep factor had reached the limit value. The maximum loading time per step was 4 hours.

Ultimate load and deformation

The ultimate load can be derived from Figure 5.3 and amounts 1120 kN.
The deformation of the pile head amounts 60 mm.
At a load of 1000 kN, the maximum difference between two rulers was 0.5 mm, see Figure 5.4 from this, it was concluded that the load was applied centric on the pile head.

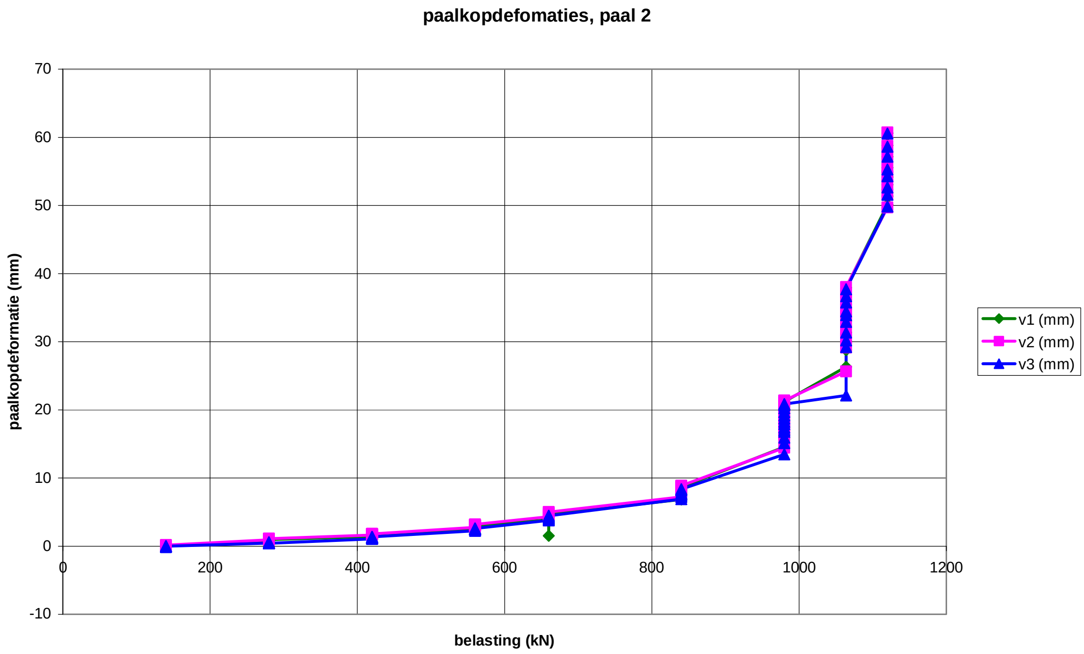


Figure 5.4 *Pile head deformation, measurements from the 3 rulers, test pile 2.*

In Figure 5.5 the head displacements during the first 540 minutes of the test as recorded by the electro optical device of IFCO are shown. A comparison with the manually taken deformations shows that the accordance between the two types of measurements is good.

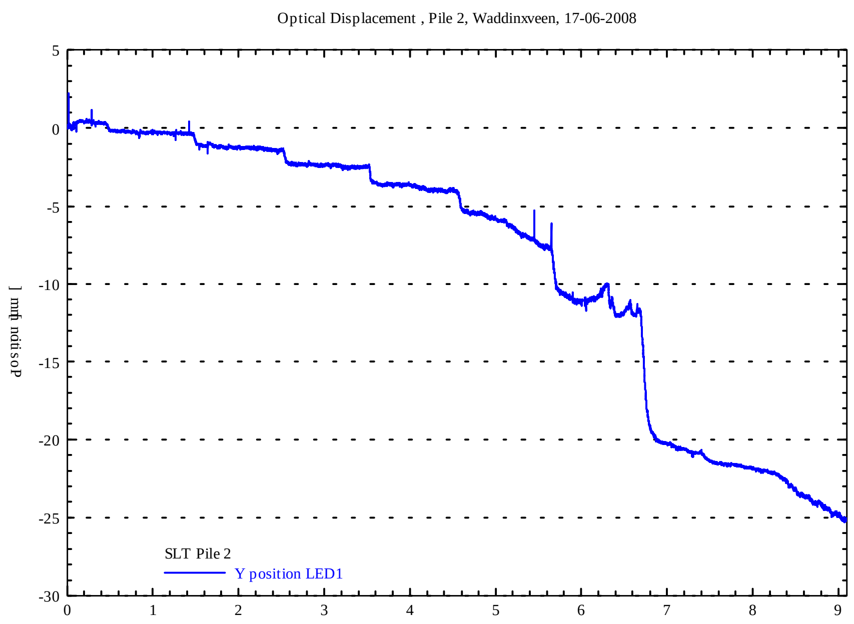


Figure 5.5 *Electro optical measurement of the vertical pile head deformation, test pile 2*

5.2.2 Strain gauge measurements

The measured values of the strain gauges are recorded as Volts on the hard disk. Deltares has settled calculation factors to determine the force in the pile. The values are based on the calibration measurements carried out by the supplier of the gauges, the calibration of the amplifier and the properties of the pile Figure 5.6. shows the calculated forces.

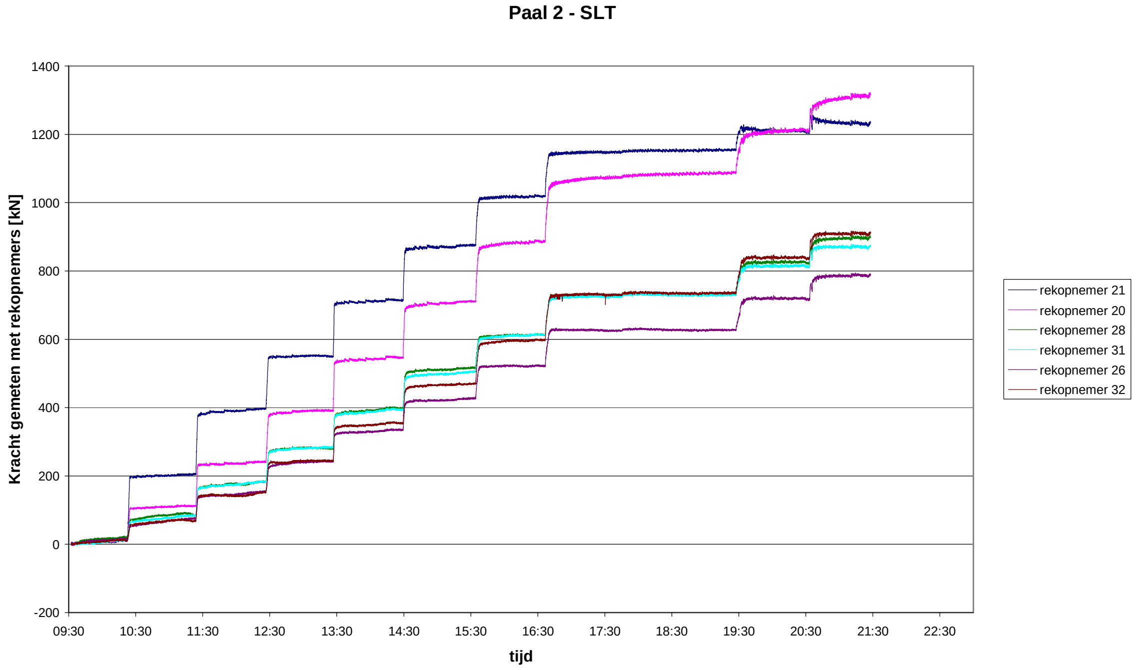


Figure 5.6 Forces in the pile, determined from the strain gauges, test pile 2

Forces in the pile

At ultimate load, the mean value of the forces in the strain transducers in the pile head amounts 1260 kN. This is in good accordance with the (corrected) reading of the load cell.
At the level of ultimate, load the mean force at the transition of the Holocene layers and the Pleistocene sand amounts 890 kN. At the level of a 0,5 m above the pile toe the mean value of the force is 845 kN. This means that the contribution of the shaft is relatively low. It is pointed out, however that the difference in the forces as measured on this level (transducer 26 and 32) is high.

5.2.3 Comparison of the measurements at the pile head

The forces derived from the strain gauges can be compared with the force measured in the pile head by the load cell Figure 5.7. shows the results. It is concluded that the strain gauges give reasonable results. The load from the strain gauges is 14% above the value from the load cell. This suggests that the stiffness is a bit overestimated.

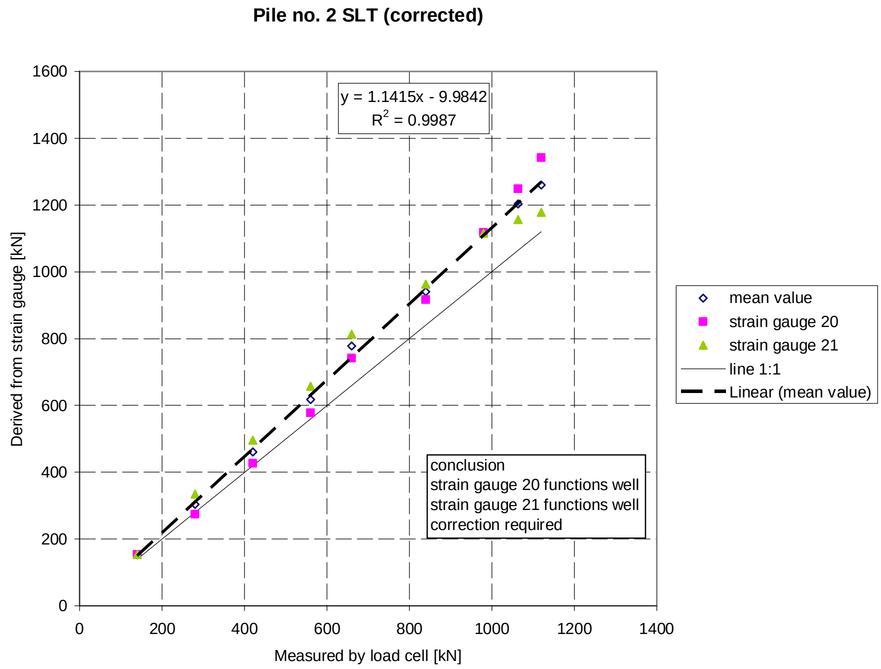


Figure 5.7 *Comparison results Load cell and strain gauges pile 2*

5.3 Test pile 1

The second static load test was performed at June 19, 2008.
On this pile a Statnamic test was already performed

5.3.1 Results of standard measurements

In Figure 5.8 the relation between time and applied force at the pile head is given. The necessity to correct the force became obvious during the execution of the test. At the start of the test, a load step of 175 kN (corrected value) was applied. Due to the lower ultimate level that was found in the first test the load step size was changed from 150 kN (corrected value) to 125 kN (corrected value). This change was performed in order to maintain the number of load steps at about 8 and maintain the necessary accuracy in the determination of the ultimate load.

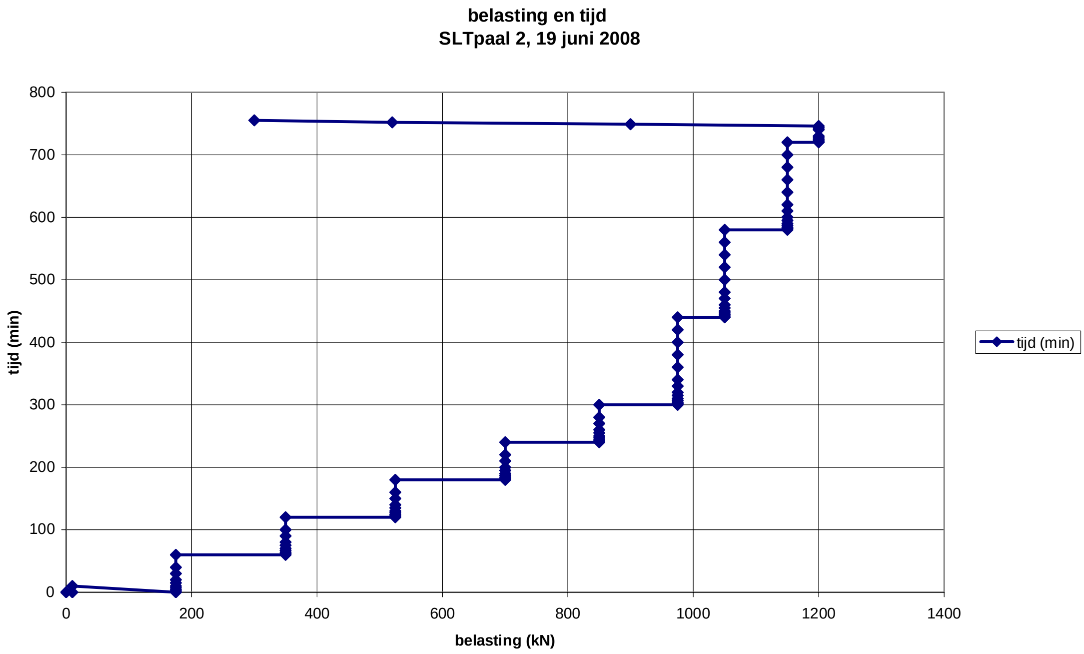


Figure 5.8 *Relation between time and the load, test pile 1*

In Figure 5.9 the relation between time and vertical deformation of the pile head is given. The pile head deformation is determined as the mean value of the three measurements from the rulers.

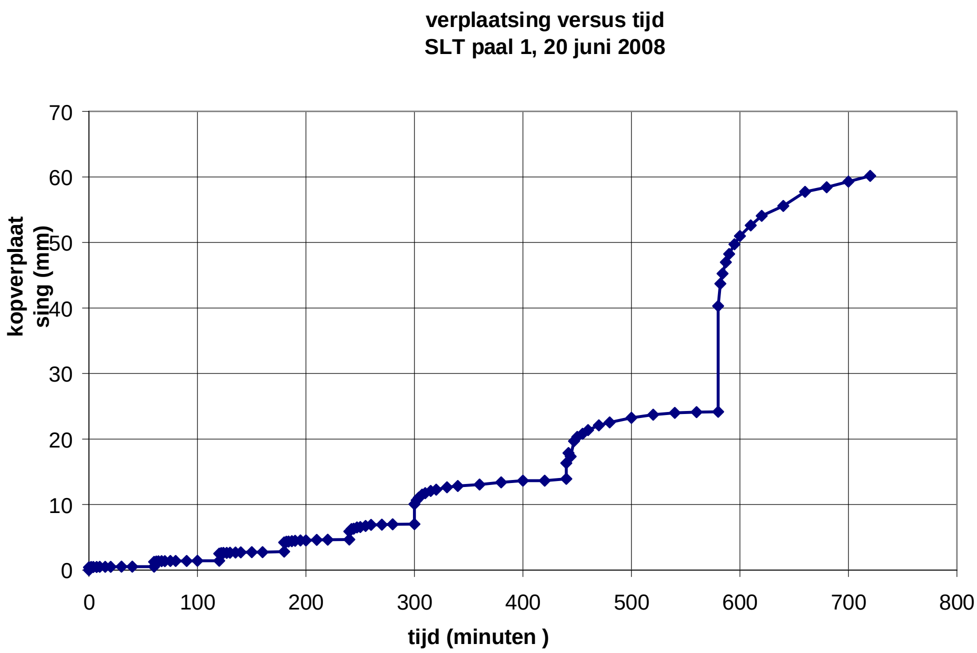


Figure 5.9 *Relation between time and pile head displacements, test pile 1*

In Figure 5.10, the three separated measurements of the pile head displacement are given in relation to the load.

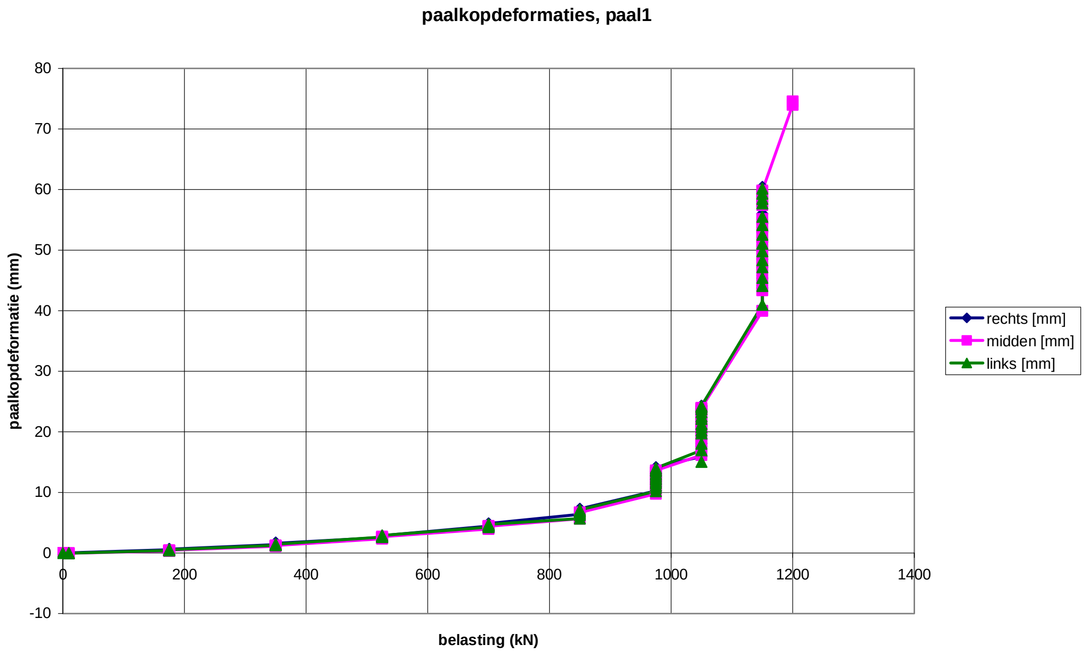


Figure 5.10 *Measurements of the separate rulers, test pile 1*

The difference between the measured displacements at a load amounts 0,7 mm at a mean level of 20 mm.

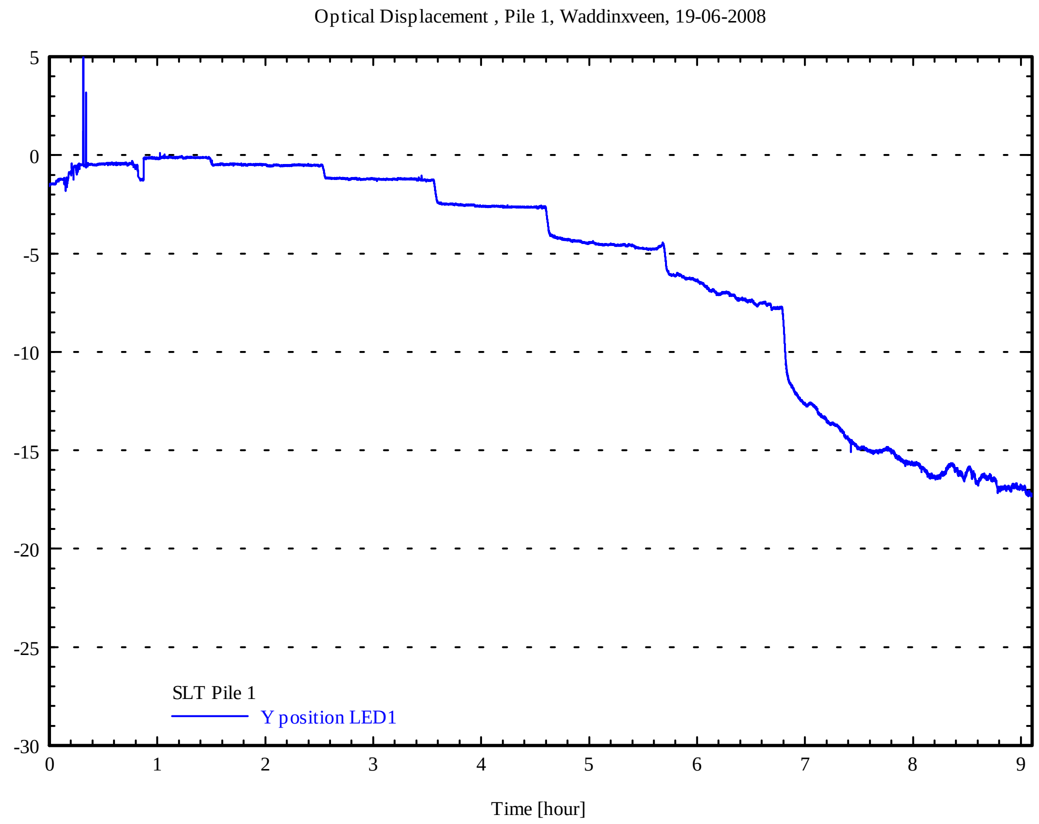


Figure 5.11 *Electro optical measurement of the vertical pile head deformation, test pile 1*

In Figure 5.11 the vertical deformation of the pile head during the first 540 minutes of the test are given. The measured values coincide well with the manual readings from the Leica leveller.

In Figure 5.12 the relation between the force in the pile head and the vertical pile head displacement is shown. The force is determined from the readings of the load cell.

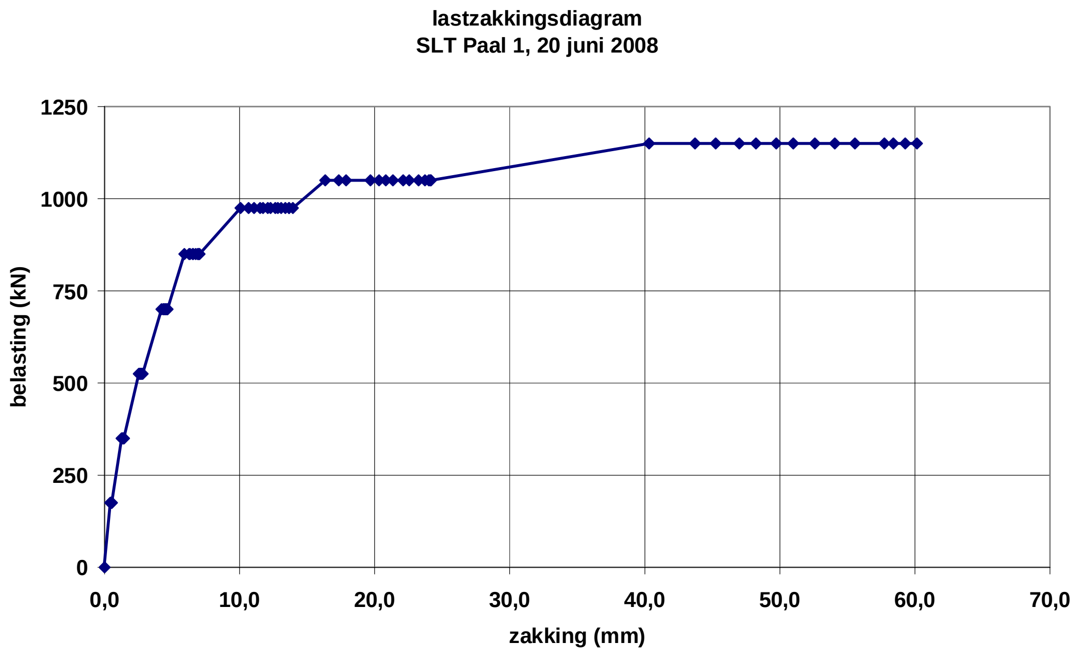


Figure 5.12 Load deformation curve, test pile 1.

Ultimate load

The ultimate load of test pile 1 is determined at 1150 kN., see Figure 5.13. De deformation of the pile head was 60 mm. From the readings of the strain gauges, it turned out that some bending had occurred in the pile head. This effect could not be observed from the pile head deformation measurements.

5.3.2 Strain gauge measurements

In Figure 5.14 the results from the strain gauges, after elaboration to forces are shown.

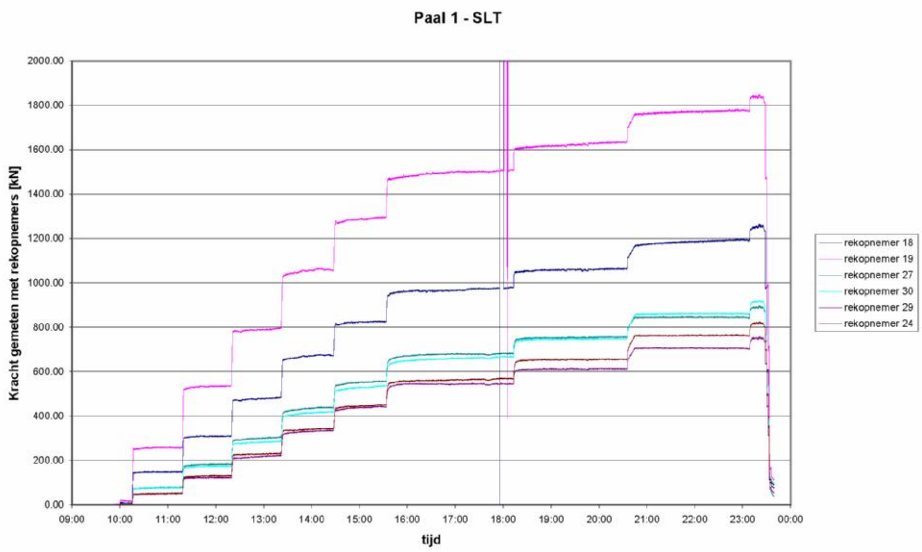


Figure 5.13 Force in the pile, determined from strain gauges, test pile 1

From the diagram, it turns out that the mean value of the force at the pile head (transducers 18 and 19) amounts 1540 kN. The force at the transition between the holocene layers and the Pleistocene sand is determined at 820 kN (transducers 27 and 30). The mean value of the force at a level of 0,5 m above the pile toe is determined at 790 kN (transducers 24 and 29). The force at the pile toe and the transition level is in good agreement with the values found in test pile 2. The force in the pile head has a large deviation from both the readings of the load cell and the measurement at test pile 2. Possibly the deviation is caused by eccentricity of the force near the pile head, though this cannot be observed from the level readings.

5.3.3 Comparison of the measurements at the pile head

The forces derived from the strain gauges can be compared with the force measured in the pile head by the load cell Figure 5.14 shows the results. The real stiffness of the pile is (about 25%) higher than the estimated value and the pile is loaded a bit eccentric. Based on the equations in Section 6.3.4, eccentricity is 17 mm.

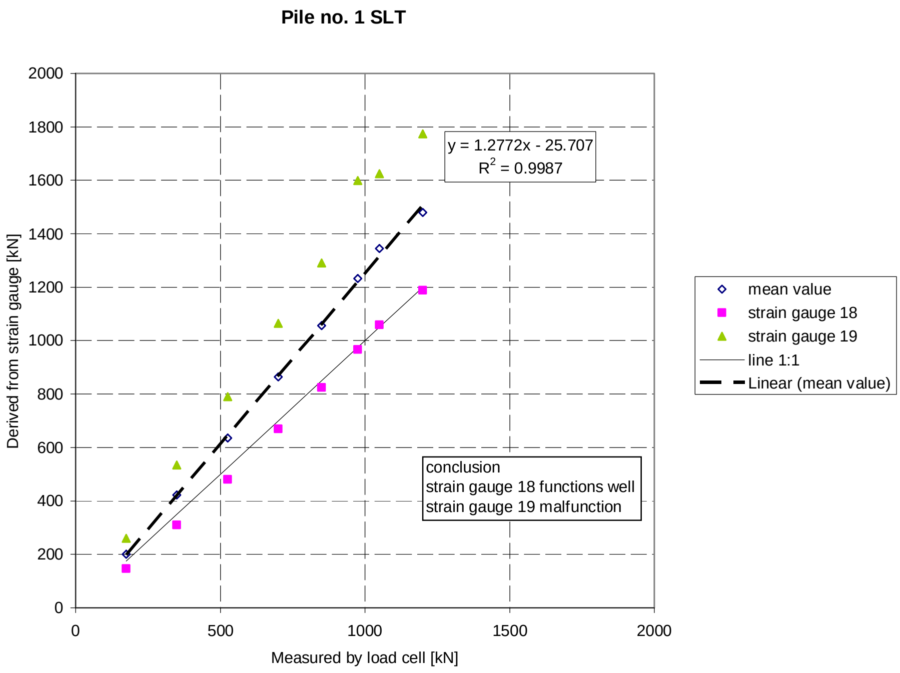


Figure 5.14 Comparison forces at pile head for pile 1

5.4 Conclusions

Table 5.1 shows the ultimate bearing capacity from the static load tests.

Pile number	State at test	Bearing capacity from force transducer [kN]	Bearing capacity from strain transducers [kN]
2	Virgin	1150	1120
1	Tested by RLT before	1260	1480

Table 5.1 Bearing capacity from the SLT

The reason why the results of the strain gauges lead to relatively large differences between the two piles is not known. Maybe the fact that Pile 2 was virgin while Pile 1 had been preloaded plays a role.

Photo 5.1 Water tanks used for static test

6 Rapid load tests

6.1 Execution RLT (Statnamic)

The RLT was carried out by using a 4 MN Statnamic apparatus of Profound (Profound, 2009). According to the draft standard, the load, displacement and acceleration were measured at the pile head. Sample rate was 4000 Hz additionally, the strains in the piles are measured at 3 levels (see Section 3.2) and the pore water pressure under the pile toe and in the soil close to the pile. The data acquisition of the transducers in the pile and the soil is done by Deltares. Sample rate was 2000 Hz. No time synchronisation has been done.

Pile 1 was loaded by 6 load steps. The load steps 1, 2 and 3 had almost similar maximum load. This pile was virgin.

Pile 2 was loaded by 6 load steps. This pile had been tested before by an SLT

6.2 Results of standard measurements

Appendix E shows the measured forces, displacements and acceleration at the pile head, together with the rapid load-displacement diagram. At the first page of the appendix a legend is given.

6.3 Results of strain measurements

The strains are measured during the RLT at the positions indicated in Section 3.2. The full strain measurements are presented in Appendix F.

It is noted that the two strains measured in the pile head are not equal. This means that moments are introduced during this test. Generally, it is believed that the average value is the real force in the pile. This reasoning is true for a linear elastic pile that is loaded almost centric. However, if relatively large eccentricity occurs, the strains and strain-rates are not equal anymore, which might influence the derived forces.

For all tests the strains at the two levels near the pile toe, the measured strains are almost equal. This means that the bending moments at those levels are small, as is expected. Since these measurements confirm the expectation, these can be used with sufficient confidence.

6.3.1 Measured forces in pile 1

The functioning of strain gauge number 19 during the static measurement was doubtful.

Figure 6.1 to Figure 6.4 shows the measured averaged forces in pile 1 during RLT. A selection of the load steps is shown. Load steps 2 and 3 had almost identical load on the pile head and are considered as repetitions of load step 1.

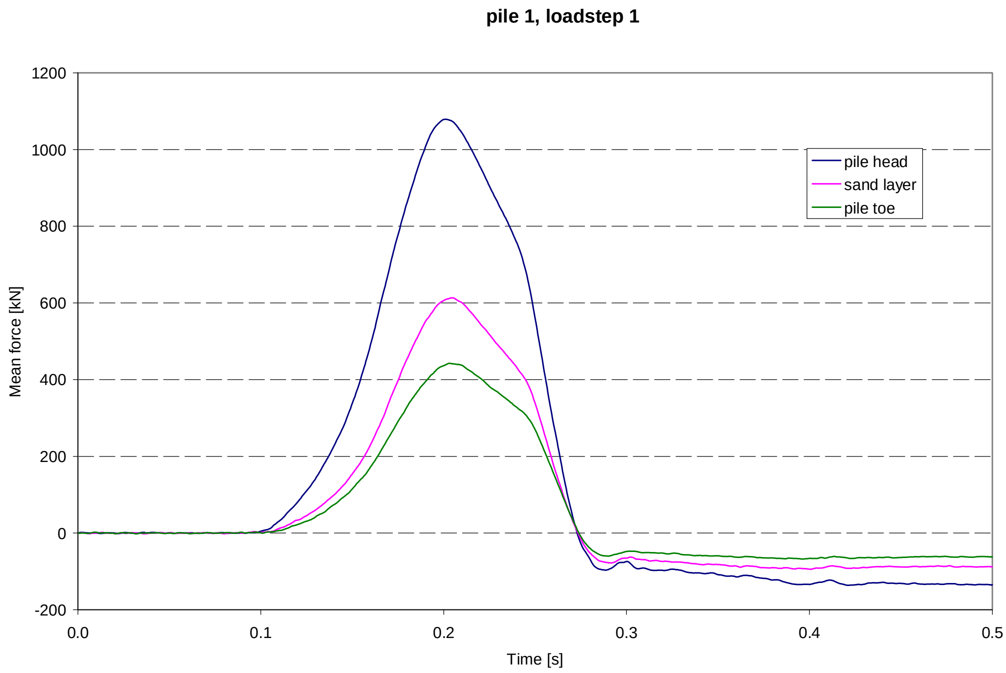


Figure 6.1 *Forces in pile 1 during RLT load step 1*

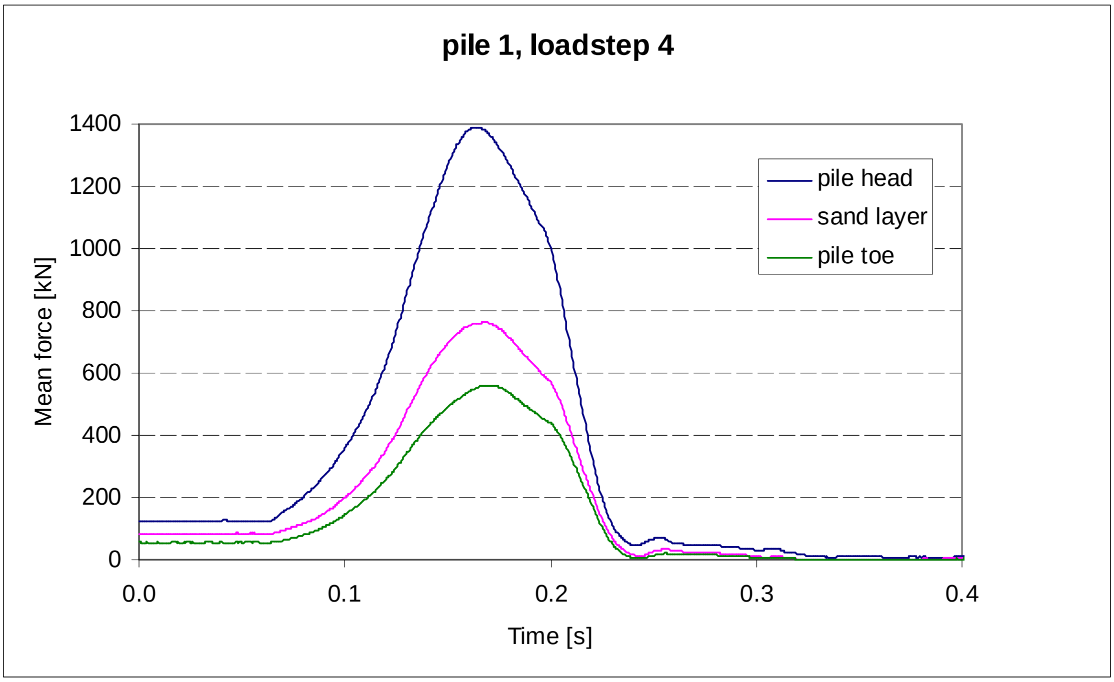


Figure 6.2 *Forces in pile 1 during RLT load step 4*

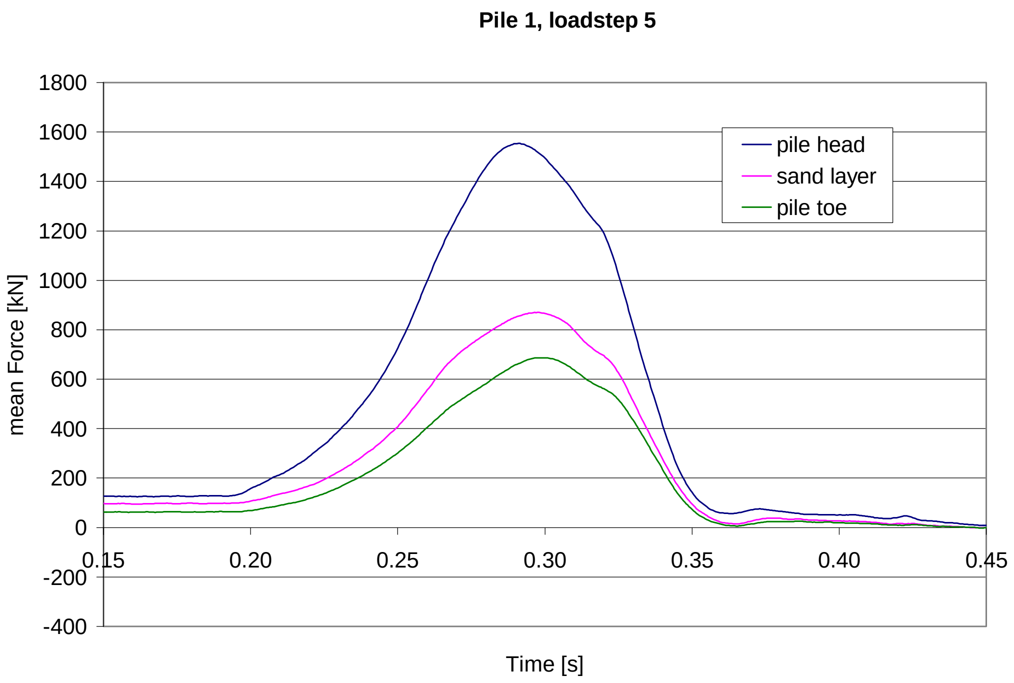


Figure 6.3 *Forces in pile 1 during RLT load step 5*

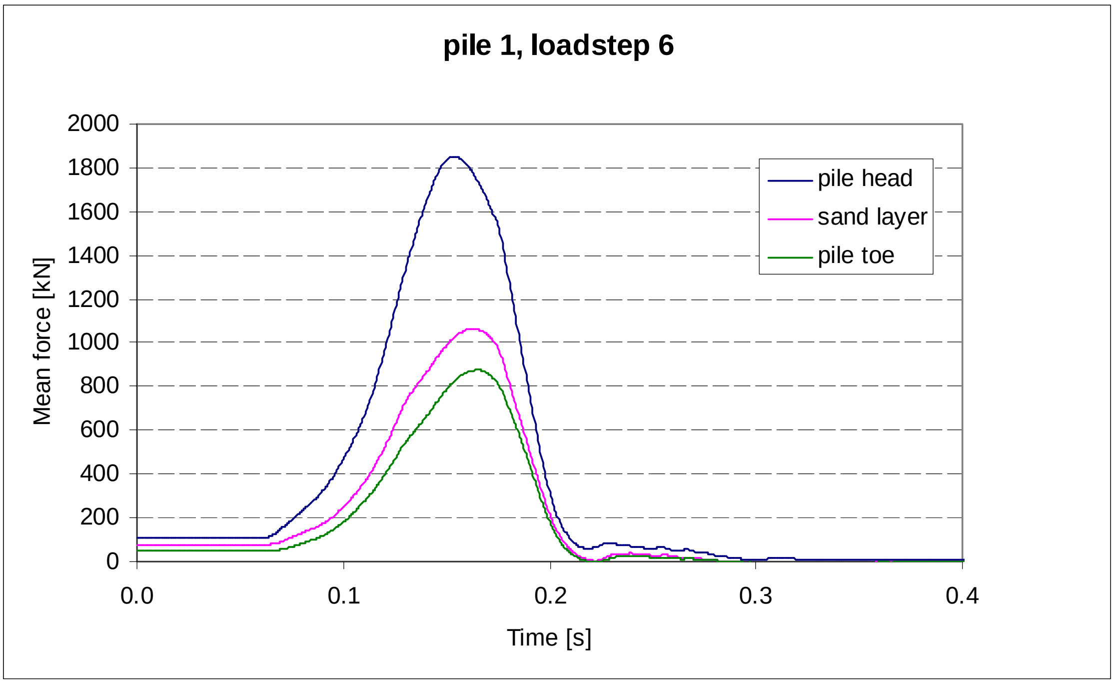


Figure 6.4 *Forces in pile 1 during RLT load step 6*

6.3.2 Measured forces in pile 2

Figure 6.5 to Figure 6.8 shows the measured averaged forces in pile 2 during RLT. All load steps are shown.

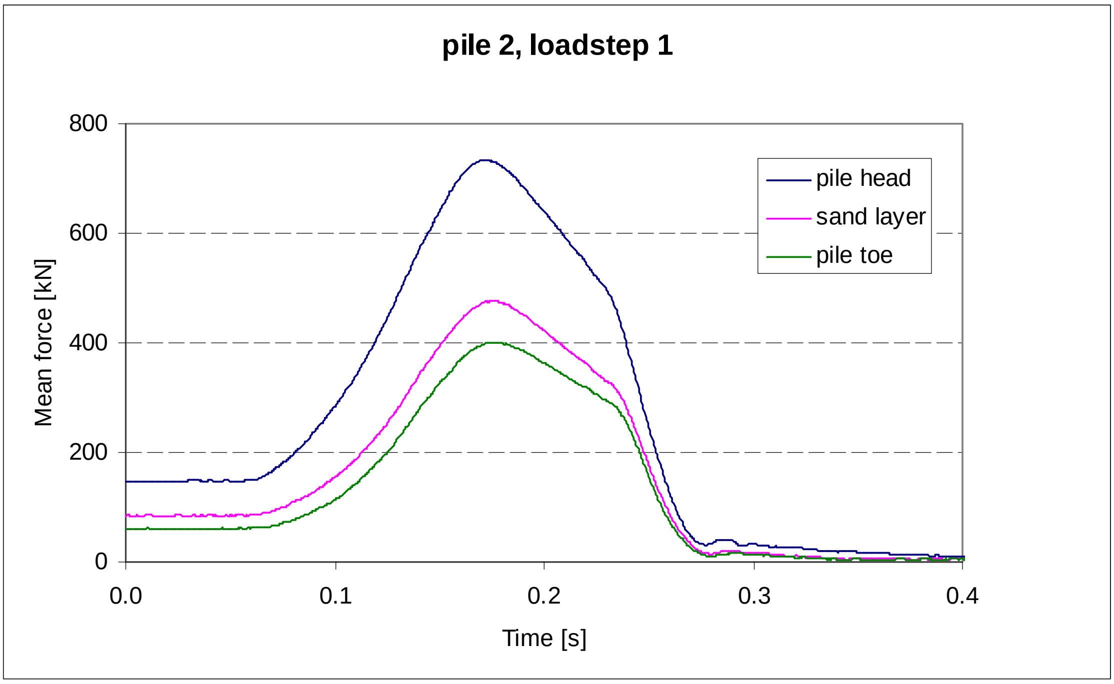


Figure 6.5 *Forces in pile 2 during RLT load step 1*

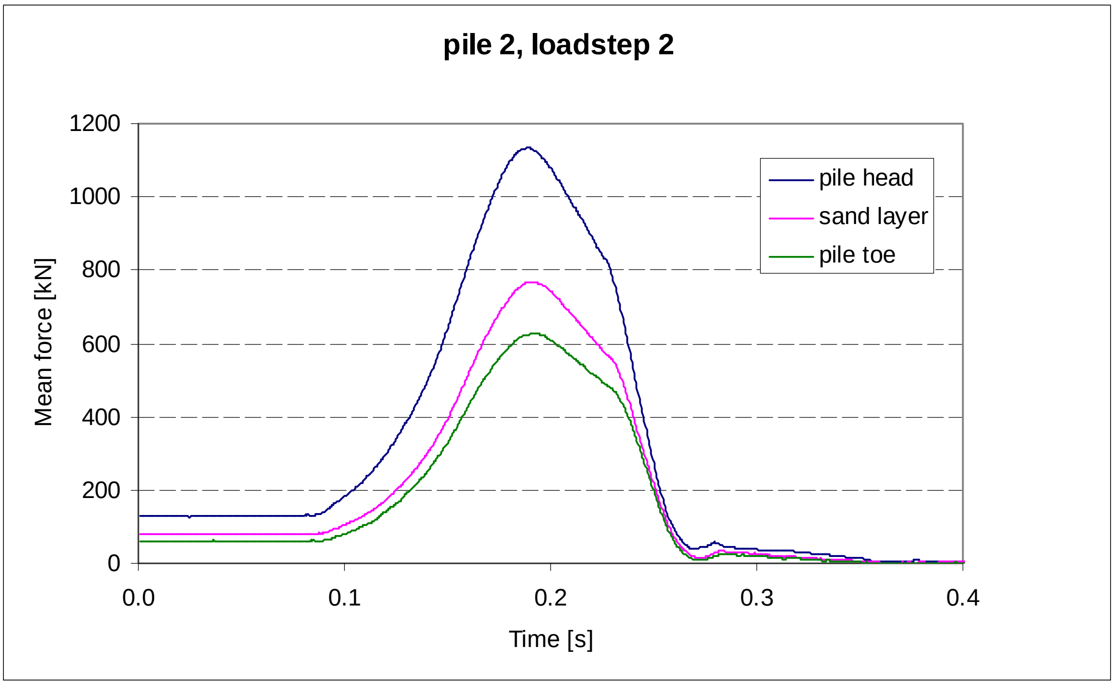


Figure 6.6 *Forces in pile 2 during RLT, load step 2*

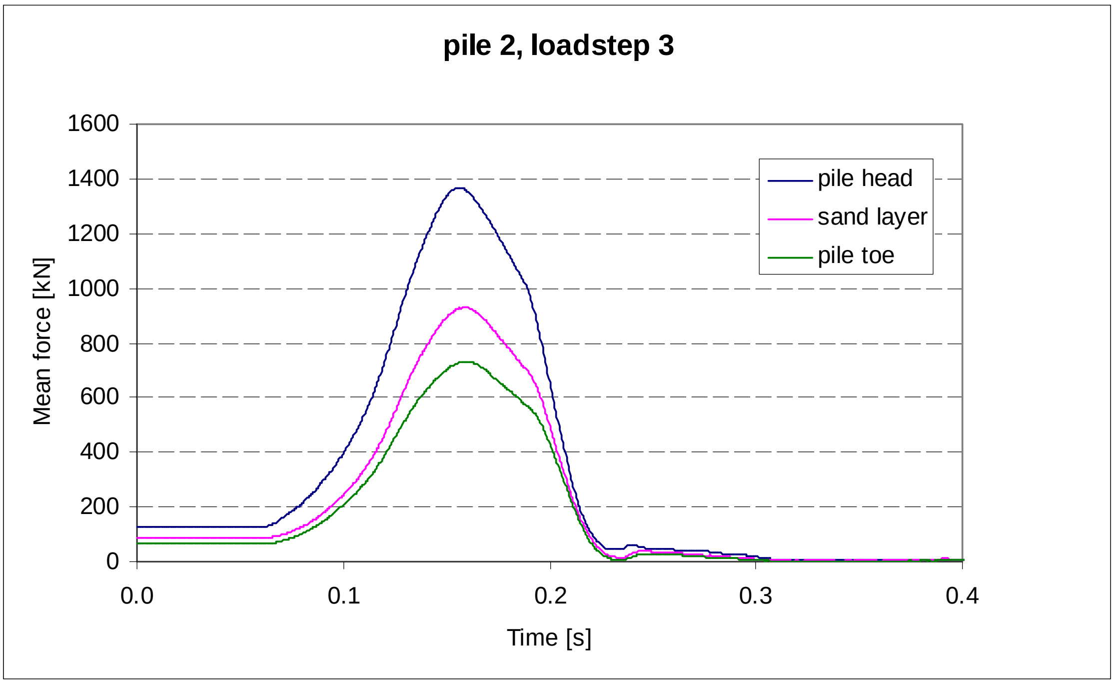


Figure 6.7 Forces in pile 2 during RLT load step 3

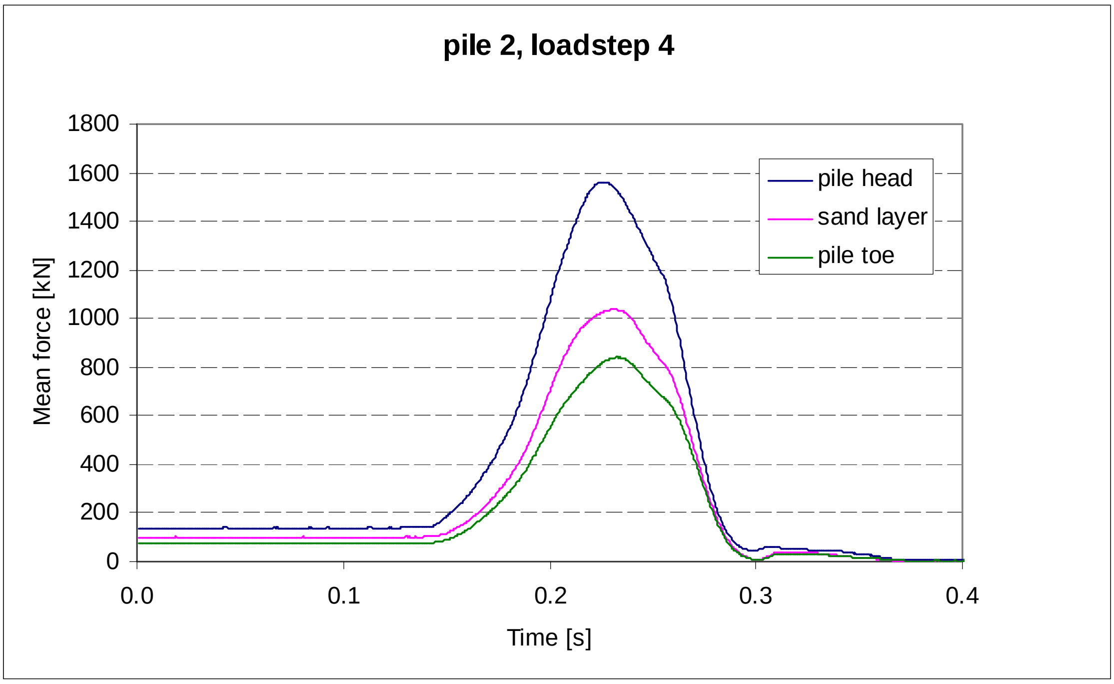


Figure 6.8 Forces in pile 2 during RLT load step 4

6.3.3 Calibration: the weight of the Statnamic device

The measured values are corrected for the final value of the force (15 sec after execution of the test). This value is assumed zero. From these corrections, the weight of the Statnamic device can be estimated, from the initial non-zero value Table 6.1 shows the readings from both the strain gauges and the load cell. The data in Table 6.1 show that the strain gauges and the load cell show almost similar values. On average, the weight of the device is

estimated by the strain gauges on 132 kN, and the load cell 128 kN. This result does not suggest that the strain gauges overestimate the forces.
The weight of the Statnamic equipment is approximately 180 kN (private communications). The SLT results suggested a overestimation of the forces from the strain gauges. This cannot be confirmed from these measurements.

Pile	Load step	Strain gauge [kN]	Load cell [kN]
1	1	134	100
	2	157	156
	3	129	120
	4	125	120
	5	125	115
	6	108	65
	average	**130**	**113**
2	1	147	185
	2	130	160
	3	127	150
	4	137	110
	average	**135**	**151**

Table 6.1 Static weight Statnamic device from strain transducers and load cell

6.3.4 Stresses due to bending moments in the pile head during loading

It should be noted that the pile head has a bending moment. For the last test on pile 2 the maximum forces calculated from the strain transducers are 1940 kN and 910 kN. This means that a bending is measured.

The stress at the location of strain gauge i is (symbols are explained below)

$$\varepsilon_i = \frac{F_i}{EA} \rightarrow \sigma_i = \frac{F_i}{A}$$

The stress in the cross section as a function of distance (x) to the neutral line is

$$\sigma(x) = \sigma_{ave} + x\frac{\Delta\sigma}{\Delta x} = \sigma_{ave} + x\frac{\Delta\left(F/A\right)}{a} = \sigma_{ave} + x\frac{|F_2 - F_1|}{A*a}$$

The maximum value is found for x = 1/2 b. The resulting bending moments are calculated by integration of the stress. This shows

$$M = \frac{b^2}{12a}\left(F_2 - F_1\right)$$

The minimum stress is calculated (compression is positive)

$$\sigma_{\min} = \sigma_{pre} + \sigma_{norm} - |\sigma_{bend}|$$

$$\sigma_{norm} = \frac{N}{2A} = \frac{F_1 + F_2}{2A}$$

$$\sigma_{bend} = \frac{\frac{1}{2} b |F_2 - F_1|}{a * b^2}$$

$$\sigma_{\min} = \sigma_{pre} + \frac{F_1 + F_2}{2A} - \frac{|F_1 - F_2|}{2ab}$$

with	σ_{pre}	the pre-stress in the concrete (4.7 MPa)
	σ_{norm}	the stress in the concrete due to the normal force (Pa)
	σ_{bend}	the stress in the concrete due to the bending moment (Pa)
	F_1	the force read from strain transducer 1 (N)
	F_2	the force read from strain transducer 2 (N)
	A	the area of the pile (= b*b = 0.35*0.35 m^2)
	b	the dimension of the pile (0.35 m)
	a	distance between the two transducers (0.24 m).

Using the dimensions of the pile and the pre-stress in the pile, for each test the minimum stress can be calculated, see Table 6.2. This Table also shows the eccentricity e of the normal force N, which lead to the moment M. The eccentricity is within the pile dimensions and, therefore, realistic.

Pile	Load step	F1 [kN]	F2 [kN]	N [kN]	M [kNm]	e [m]	Stress (min/max) [MPa]
1	6	727	2772	1750	87	0.05	6.9 / 31.1
2	4	1940	910	1425	44	0.03	11.5 / 23.7

Table 6.2 Estimated tension stresses in pile head

Note: the resulting eccentricity for pile 1 exceeds the limiting value of 10% of equivalent diameter of the pile (10% of 0.39 m).

Figure 6.9 shows the development of the eccentricity during load step 3 at Pile 1. The loading starts at 1.8 s, the maximum load is reached at 1.91 s. The loading phase is about 110 ms. After this maximum, a quick decrease of the load is observed. The pile is fully unloaded at 1.97 s, so the unloading phase takes about 50-60 ms.

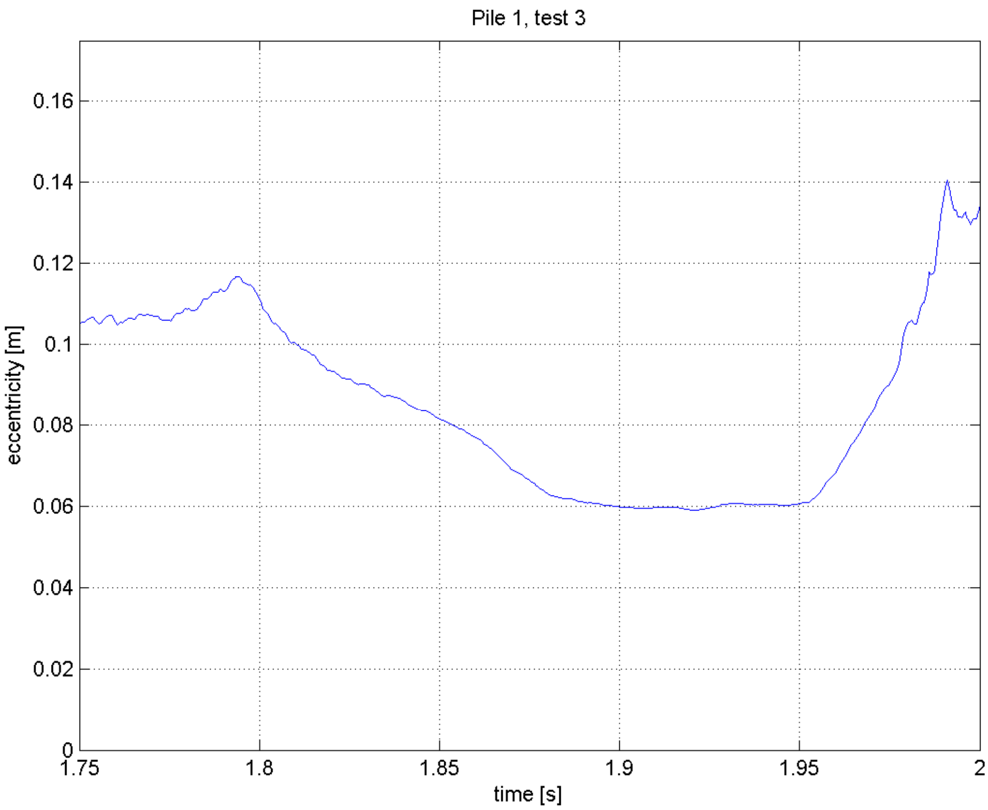


Figure 6.9 Eccentricity measured at pile head 1 during load step 3

The conclusion is that in the measured direction relatively high bending moments are observed. This does not lead to tension forces. From visual inspection, it is known that the position of the Statnamic device above pile 1 had also in the direction perpendicular to the line through the strain gauges a similar eccentricity (order 5 cm). This means that the extreme position a small tension stress is expected. We recommend using of four strain transducers in the pile head.

6.4 Pore water pressure measurements

6.4.1 Pile 1: pile toe only

Figure 6.10 shows the pore water pressure at the pile tip during RLT for pile 1, load step 6. The measured value shows large vibrations. This signal is judged as unreliable, the pore water pressure measurement for pile 1 during RLT will not be taken into account.

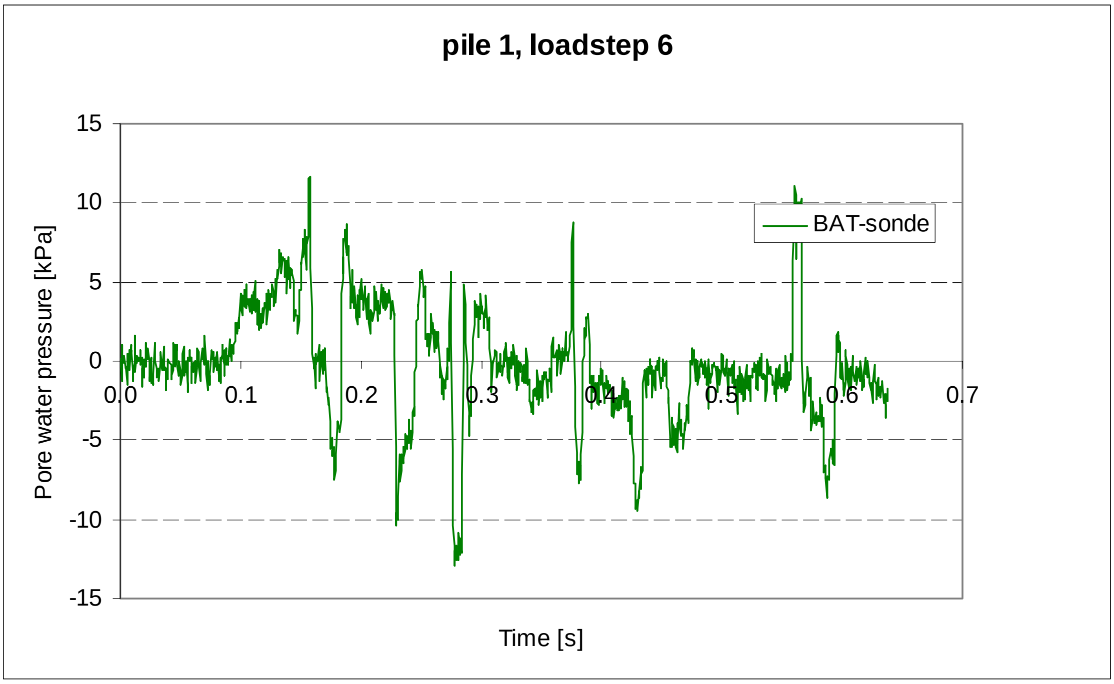


Figure 6.10 Pore water pressure from BAT at pile toe, pile 1, load step 6

6.4.2 Pile 2: pile toe and close to the toe

For pile 2, the pore water pressure is measured at the pile toe and close to the pile toe. Some mechanical improvements to the BAT are made (see Chapter 3).

Figure 6.11 to Figure 6.14 show the measured pore water pressures. Under the pile is marked with toe, in the soil is marked with soil.

Firstly, it is observed that the vibrations in the Bat are indeed removed for the smaller loading. Nevertheless, for higher loading these vibrations occur again. It is noted that these vibrations occur in the unloading phase of the test. In this phase, the accelerations of the pile are relatively high. Therefore, it is reasonable that these vibrations related with the dynamical behaviour of the pile.

Secondly, it is observed that the pore water pressures in the soil are much higher then those under the pile toe. The ratio is about a factor 6. Under the pile toe, a higher value is expected, not a lower value. Moreover, the development of the pore water pressure under the pile toe is quite slow, a negative value is finally reached after the test is finished. This behaviour is unexpected. At this moment, it cannot be explained from the physics of the system. The most plausible explanation is the assumption that the BAT cannot measure at the required rate. Therefore, the pore water pressure measurements at the pile toe are judged not reliable.

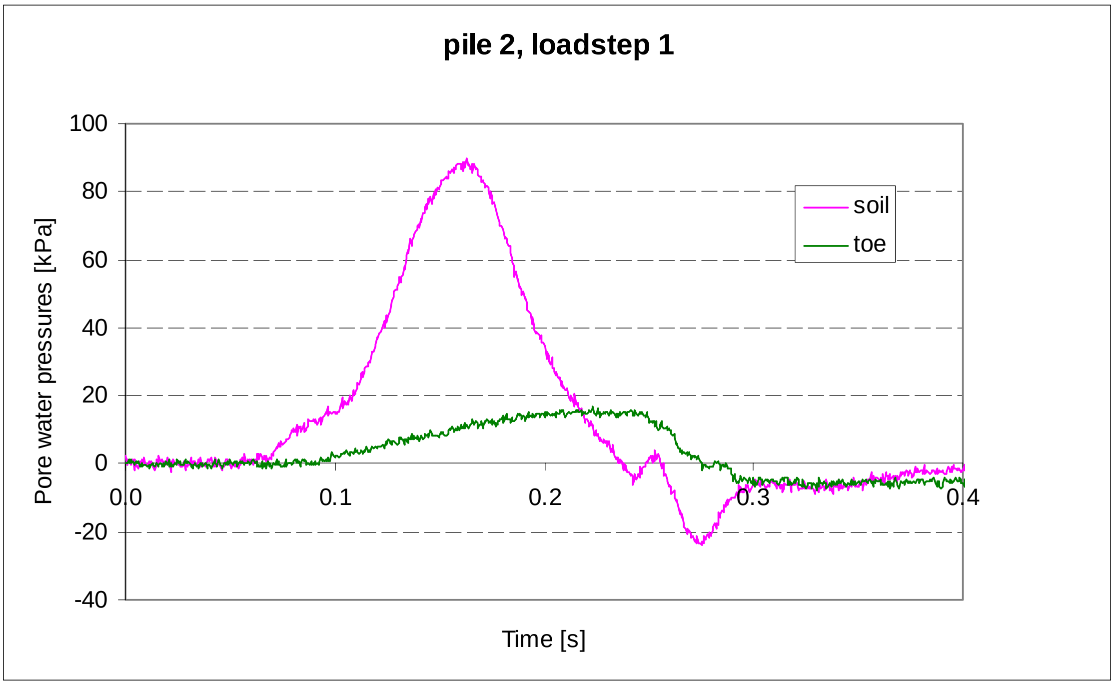


Figure 6.11 Pore water pressure, pile 2, load step 1

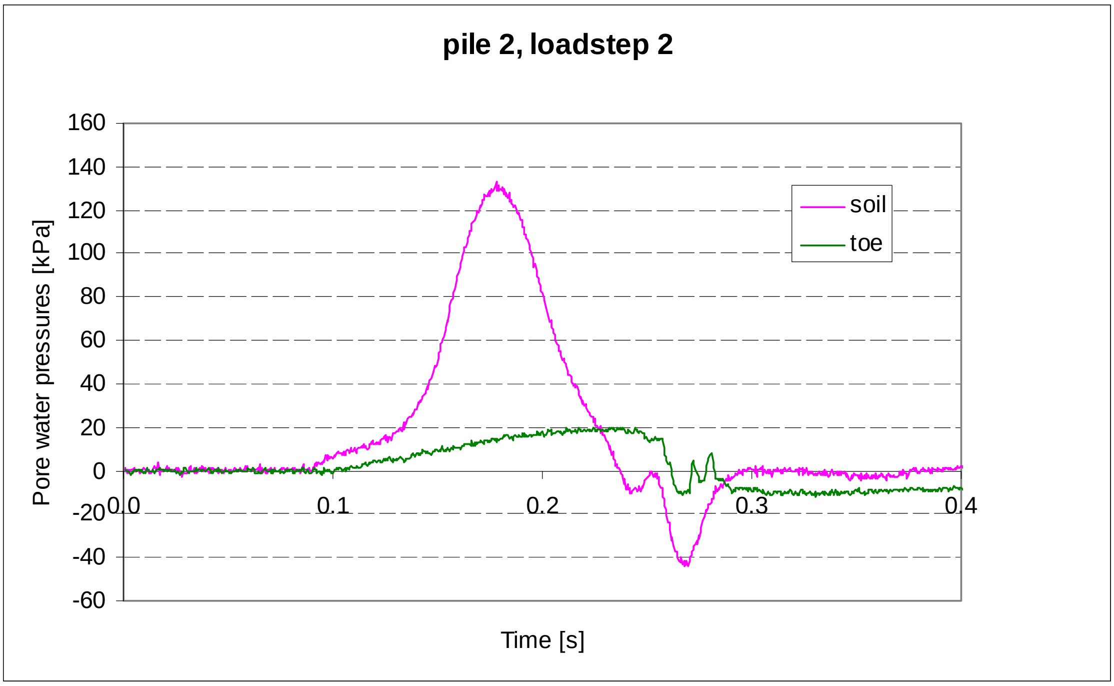


Figure 6.12 Pore water pressure, pile 2, load step 3

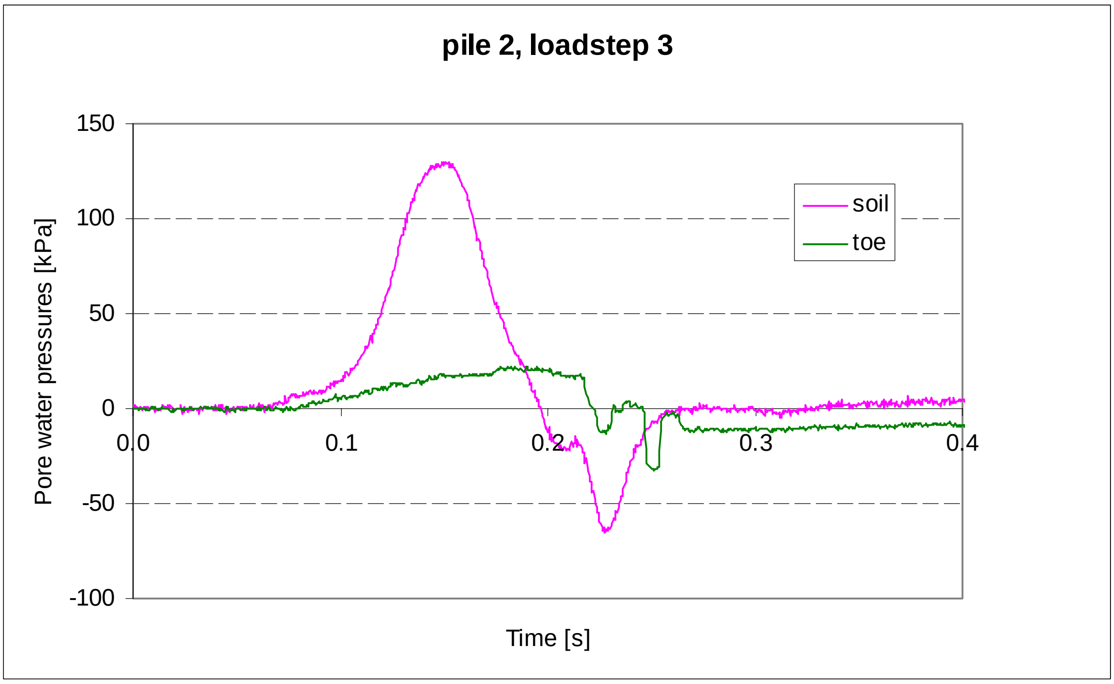


Figure 6.13 Pore water pressure, pile 2, load step 3

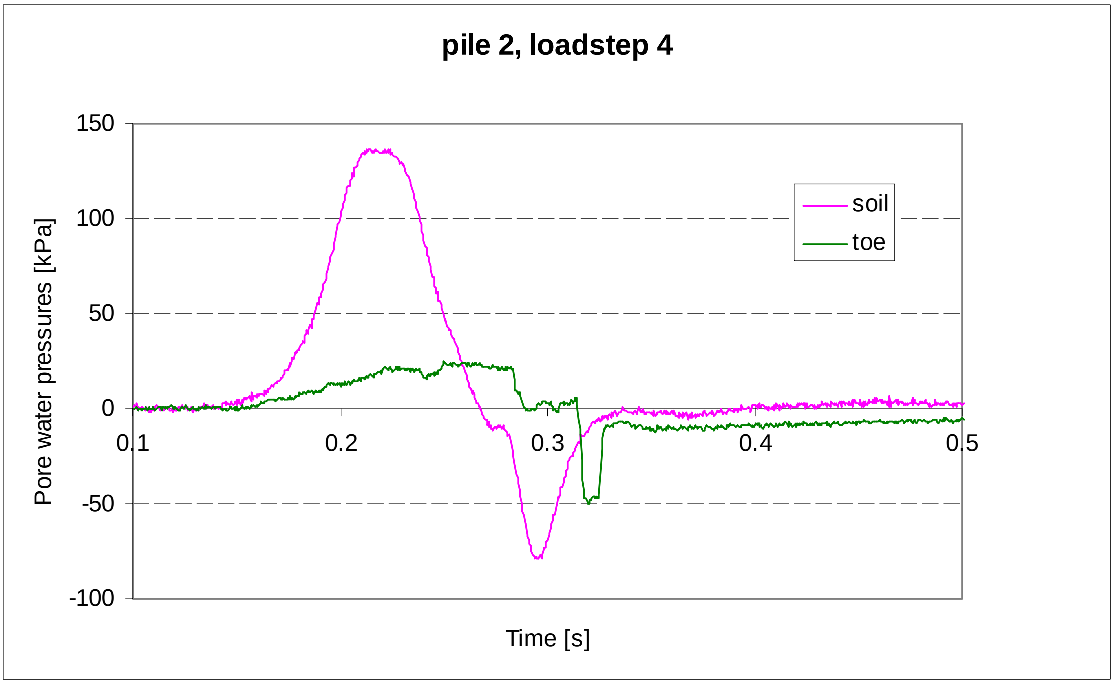


Figure 6.14 Pore water pressure, pile 2, load step 4

In the soil nearby the pile, similar measurement is carried out by [Hölscher, 1995] in the case for Delft. There, the maximum value was 80 kPa. Here, the maximum value is 137 kPa. The higher value might be explainable from the larger cross-sectional area of the pile (Delft 25*25 cm^2, Waddinxveen 35*35 cm^2), and probability a finer (less permeable) sand in Waddinnxveen. The value measured in the soil is therefore realistic.

The pore water pressure shown in this Section is the increase with respect to the hydrostatic value (95 kPa = 9.5 m water depth). The measurement starts with an increase of pressure, so the phenomenon is compression of the fluid. Later on, under-pressure of about 80 kPa is observed. At that moment, the pore water pressure is 95-80 = 15 kPa (= 1.5 m water depth). The negative value is substantial. Cavitation (occurring at -100 kPa) is still far away, even for his short pile. However, this measurement at 0.7 m from the pile gives no exclusive on the pore water pressures in the soil directly under the pile toe.

The initial increase of pore water pressure is in agreement with the results of transducer 3 in the centrifuge tests [Huy, 2008], which is at a comparable position (2 D from the pile toe). However, the strong decrease is in the centrifuge tests not observed at this distance, but it is observed at the transducer at the pile toe and the transducer at 2.5D under the pile toe level.

6.5 Comparison of load steps

Table 6.3 shows the observed maximum values during RLT on pile 2. The relative values, shown in Table 6.4, suggest that, apart from the pore water pressure in the soil, the behaviour of the pile is linear. The pore water pressures in the soil at load step 2 are outside the general trend.

Load step	Level 1 Pile head [kN]	Level 2 Sand layer [kN]	Level 3 Pile toe [kN]	Pore water Toe [kPa]	Pressures Soil [kPa]
1	734	477	401	16.7	89.6
2	1134	768	628	20.1	133.1
3	1367	930	732	22.1	130.2
4	1562	1038	840	24.9	136.7

Table 6.3 Maximum values observed during load steps RLT pile 2

Load step	Level 1 Pile head [kN]	Level 2 Sand layer [kN]	Level 3 Pile toe [kN]	Pore water Toe [kPa]	Pressures Soil [kPa]
1	47%	46%	48%	67%	66%
2	73%	74%	75%	81%	97%
3	88%	90%	87%	89%	95%
4	100%	100%	100%	100%	100%

Table 6.4 Relative values of maxima values observed during load steps RLT pile 2

6.6 Conclusion

From the measurements in the pile and the soil, it is concluded that:

- The pile is loaded eccentric. Since only two strain transducers are placed in the pile head, a proper calibration of the stiffness of the pile cannot be made.
- Furthermore, the strain measurements are realistic.
- The bat pore water transducer did not capture the dynamic pore water pressure.
- The PR-pore water transducer showed that pore water pressures are generated during loading.

7 Dynamic load tests

7.1 Execution Dynamic Load Test (DLT)

The DLT measurements comprise of a small number of blows on a pile, which has already been driven into the ground (re-drive). Sensors on the pile measure the acceleration and strain, from which the velocity and force are derived. The recorded signals are subjected to analysis in a computer after actual pile driving. For this process, called signal matching, specialist software is used in which the static soil resistance is calculated by effectively matching a suitable measured signal to a calculated (theoretical) one. The software used in this project is DLT Wave from Profound. Different theories are available such as the TNO method, the Case method and the Impedance method. In this project, the TNO method is used. Typically, the upward travelling signals are matched in this process as it contains the most information of the subsoil.

For the measurements, the transducers were attached at approximately 2x the diameter of the pile, i.e. at 700 mm from the pile top. The pile length from transducer to pile toe was therefore 9.8 m. A part of the ground around the piles was excavated in order to protect the transducers from being driven into the ground. The resulting pile penetration after excavation was approximately 9.3 m.

The hammer used was a hydraulic hammer Junttan HHK 4A from Vroom Funderingstechnieken.

The re-drive was conducted over less than 0.5 m. After the measurements were completed and the equipment had been removed, the piles were driven to depth for future use.

7.2 Results of standard measurements

For both piles, a suitable blow was used for further analysis with the program DLT-Wave from Profound. The results for the mobilized static resistance are presented in Table 7.1. The detailed results from the matching analysis are presented in Appendix G.

Pile	Blow	Mobilized static resistance shaft	Mobilized static resistance toe	Total mobilized static resistance
		[MN]	[MN]	[MN]
1	2	0.368	1.016	1.384
2	2	0.307	1.158	1.465

Table 7.1 Mobilized static resistance

During the DLT no strain measurements and pore water measurements are done.

8 Reliability of the strain measurements

8.1 Introduction

In the previous chapters, it is observed that the results of the strain gauges are not always in agreement with the results of the load cells. This chapter gives a suggestion how to solve this problem.

8.2 Static tests

During the static tests, it is observed that the differences between the two piles measured with the load cell are small. The result measured with the strain gauges show much more variation:

- For pile 2, see Figure 5.6, the strain gauges at the pile head give some difference. At the pile toe some bending it observed, which is on physical reasons quite unexpected. It shows that the reliability of the strain gauges is limited and their behaviour in the pile has some non-linearity. This must be taken into account.
- For Pile 1, see Figure 5.13, the strain gauges at the pile head shows large bending, while at the deeper levels, no strong deviations are seen. It seems reasonable to assume that strain gauge 19 has a problem.

The results of strain gauge 19 can be ignored or corrected. For the static test, this will turn out to be the same, since the results of strain gauge 18 fits perfectly on the result of the load cell (see Figure 5.14). The correction factor for strain gauge 19 is 1/1.6 = 0.63.

8.3 Rapid tests

For the rapid test on Pile 1, the discussion on reliability has some consequences. Ignoring the results of strain gauge 19 is not possible, since this leads to lower forces in the pile head than in the pile toe. Therefore, correction of the measured value is the only possible solution.

Appendix H shows the results for the three final stages. Again it is observed that the pile was loaded eccentric.

Table 8.1 shows for the final three stages the results of the measurement at the moment of maximum force in the pile head (calculated according to the formulae in Section 6.3.4).

Pile	Load step	F1 [kN]	F2 [kN]	N [kN]	M [kNm]	e [m]	Stress (min/max) [MPa]
1	4	474	1440	957	43.7	0.046	6.8 / 18.3
1	5	550	1600	1075	47.5	0.044	7.2 / 19.7
1	6	689	1882	1286	53.9	0.042	8.1 / 22.3

Table 8.1 Estimated tension stresses in head Pile 1 after correction strain gauge 19

The resulting eccentricity exceeds the limiting value of 10% of the equivalent diameter of the pile. No tension stress is observed.

For Pile 2 the correction has no influence.

8.4 Conclusion

It is reasonable to correct the results of strain gauge 19 in Pile 1 for an error. The reason of this problem is not known.

In this prefabricated piles the accuracy of the strain gauges is reasonable. However, deviation in the order of 10 % is possible.

Both piles are loaded eccentric. For Pile 1 the eccentricity is outside the range prescribed by the Standard.

9 Discussion, conclusions and further work

9.1 Conclusion

This report presents the results of the field test June 2008 at Waddinxveen. Two piles are tested by SLT, RLT and DLT. The measured signals are presented.

The evaluation of debatable aspects in the measurements leads to the following conclusions:

1) The strain gauges at Pile 2 showed a 14 % higher value; the strain gauges at pile 1 showed a 25 % higher value.
2) The suggestion that something is wrong with strain gauge 19 in Pile 1 is not confirmed from the calibration of the strain gauges using the static weight of the Statnamic device.
3) During the RLT both piles, but especially pile 1, is loaded eccentric, outside the range prescribed by the draft Standard.
4) The BAT-transducers are not able to measure pore water pressures at sufficient high rates for RLT.
5) The pore water pressure build-up close to the pile is observed; excess pore water pressures are up to 130 kPa, negative values to -80 kPa.

9.2 Further work

The following aspects can be evaluated from these tests:

6) The derived bearing capacity from the RLT and DLT, comparison with results of the tests.
7) The distribution of the friction along the pile and the toe resistance, comparison with results of the tests.
8) Comparison of the measured bearing capacity with the predicted bearing capacity.
9) The influence of excess pore water pressure on the bearing capacity during RLT.

10 References

[Deltares, 2008]
report: CUR H410 Paaltesten, Draaiboek proefbelastingen veldproef
report Deltares, May 2008 (in Dutch)

[van Dijk, 2007]
Van Dijk, D.
Ontwerp veldproef snelle paaltest Waddinxveen
report GeoDelft, June 2007 (in Dutch)

[Brassinga, 2008]
Brassinga, H.E.
memo ‘rekmetingen in palen Waddinxveen’ dated 2 September 2008

[Hölscher, 1995]
Hölscher, P.
Dynamical Response of saturated and dry soils
PhD-thesis, Delft University of Technology, February 1995, DUP, Delft, 1995

A Realised execution scheme

Activity	Pile 1	Pile 2
CPT	16 April 2007	16 April 2007
Pouring concrete piles	14 April 2008	14 April 2008
Pile driving	17 May 2008	17 May 2008
Static test	19 June 2008	17 June 2008
Rapid test	16 June 2008	20 June 2008
Dynamic test	25 June 2008	25 June 2008

Table A.1 Execution dates of the main activities

B Results CPT

Before installation of the piles, two CPTS are done at exactly the locations of where the piles will be driven, coded S01 enS02

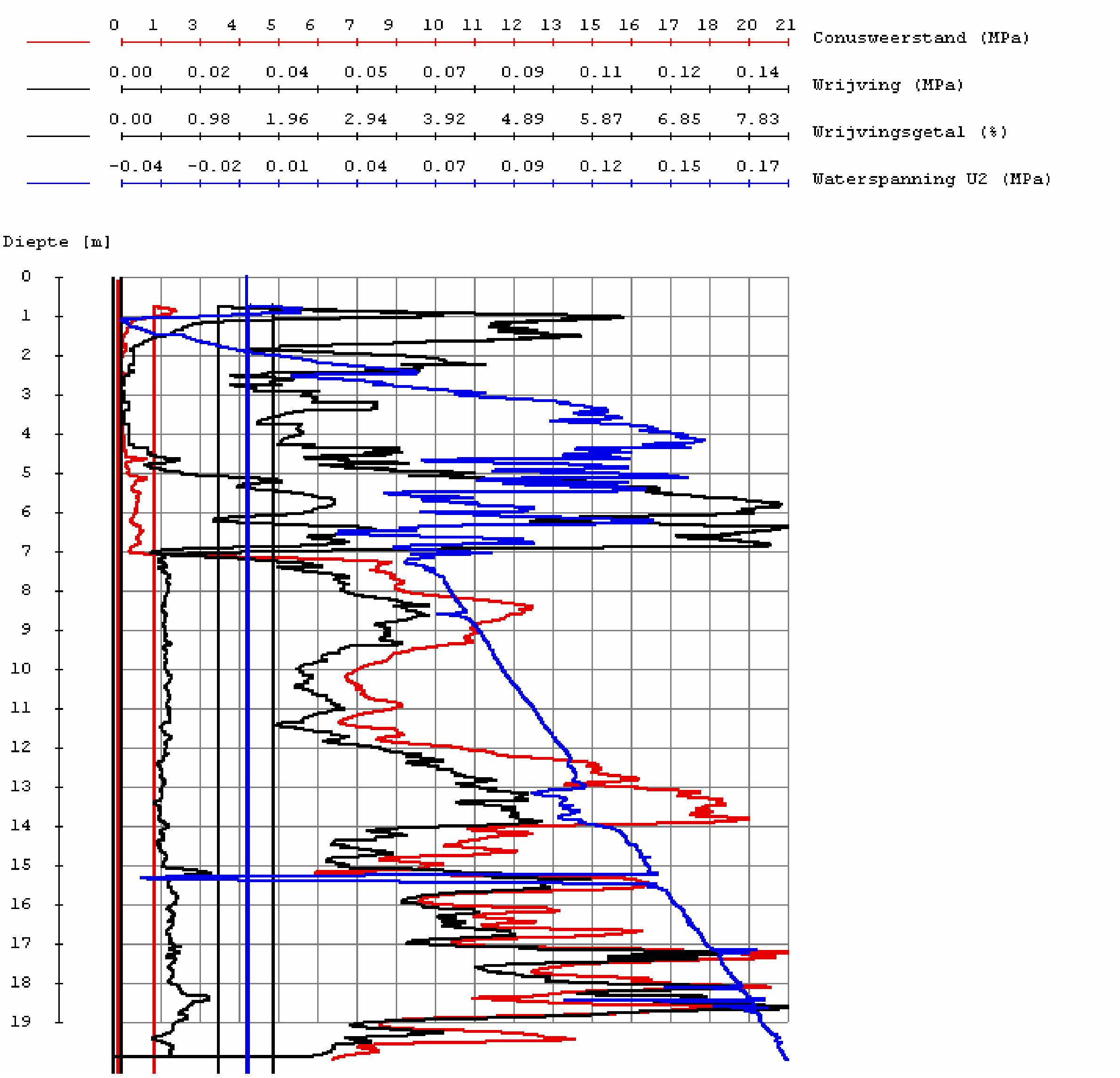


Figure B.1 CPT S01

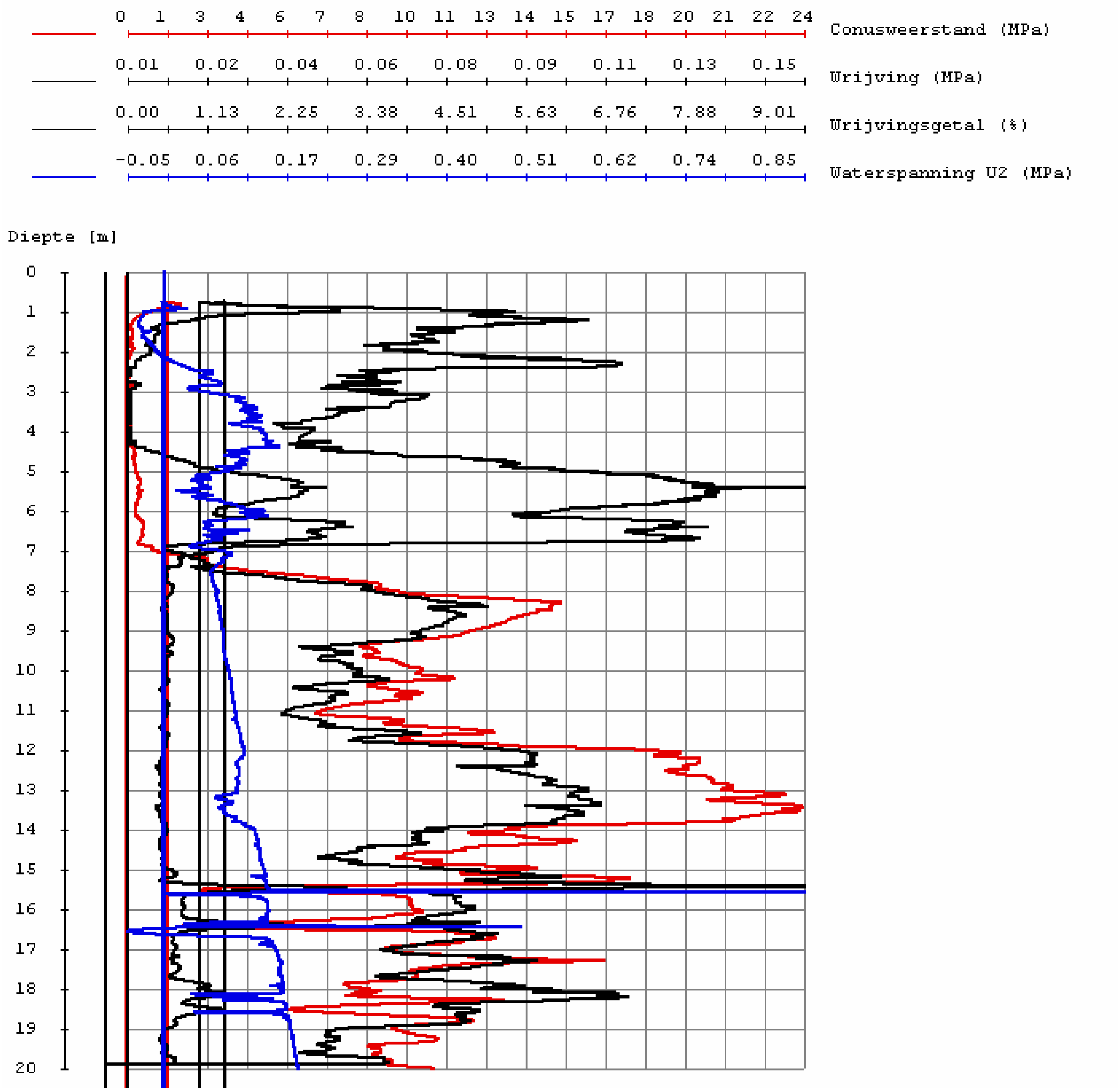


Figure B.2 *CPT S02*

C Design of the pile

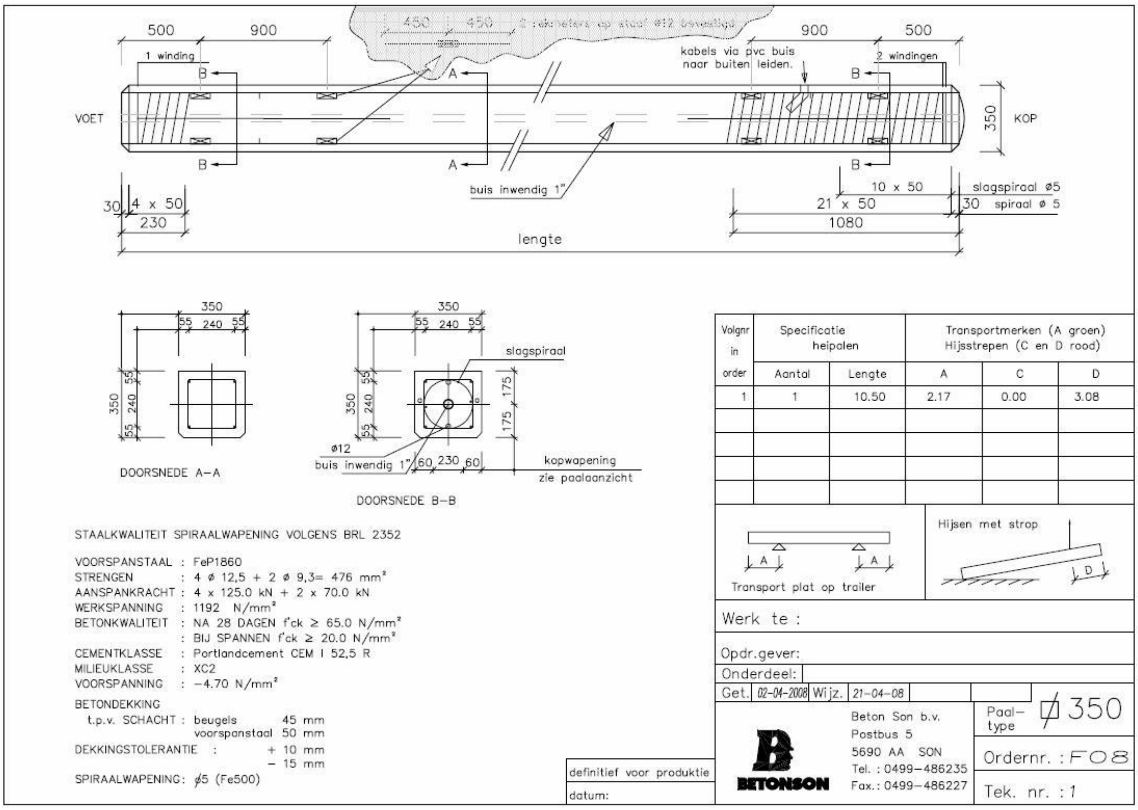


Figure C.1 *Detailed design of test piles*

D Overzicht data bestanden

Pile 1	SLT	
	RLT	load step 1
		load step 2
		load step 3
		load step 4
		load step 5
		load step 6
Pile 1	SLT	
	RLT	load step 1
		load step 2
		load step 3
		load step 4

Table D.1 Directory structure on Cd

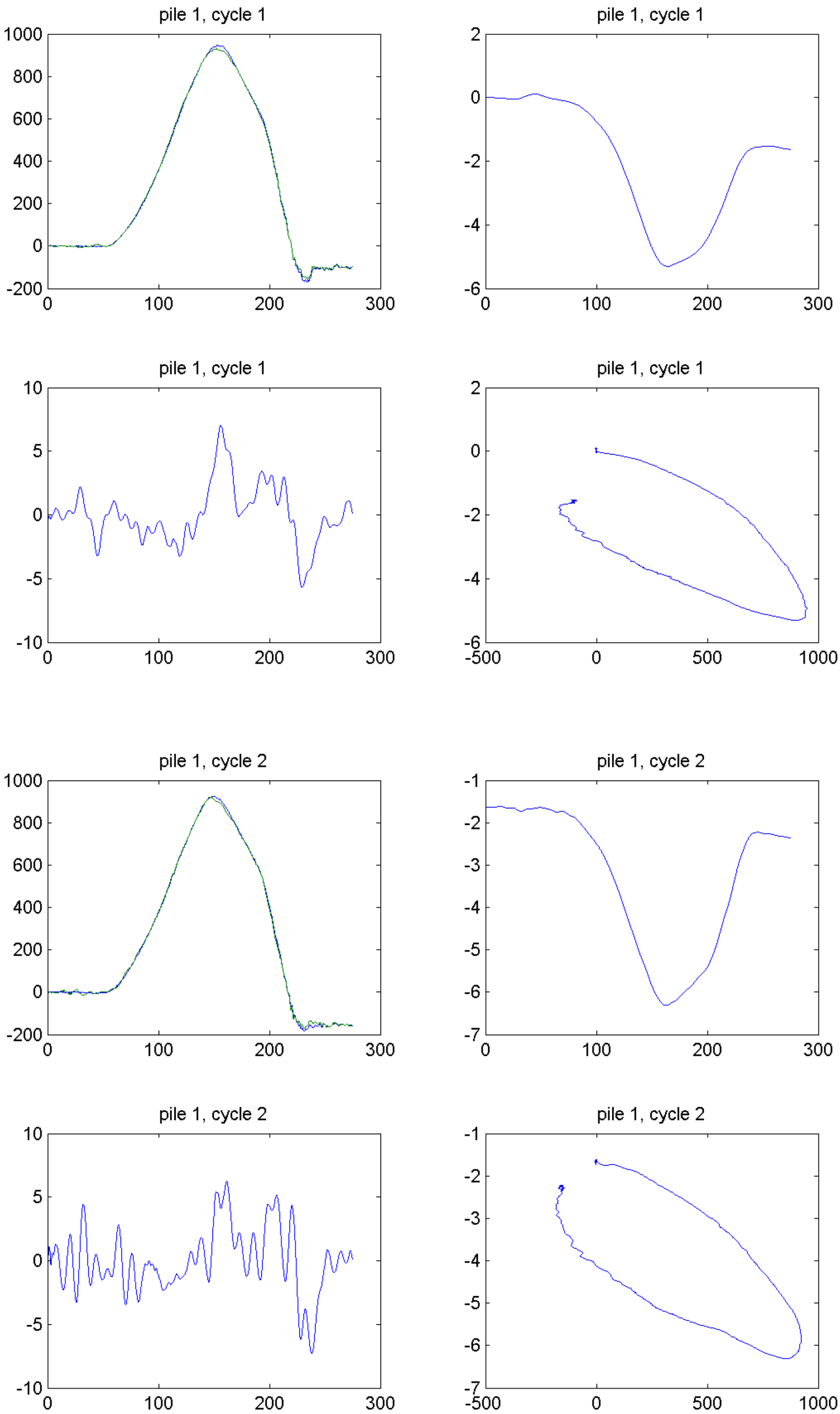
Each directory contains 2 files:

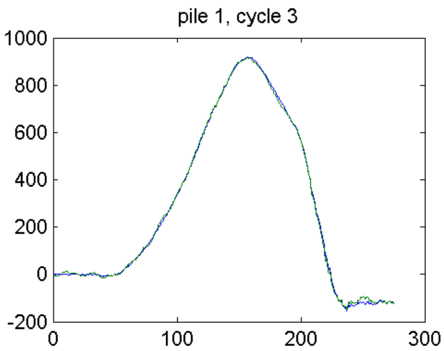
1) The measured data at the pile head
   for SLT: Force and displacement.
   for RLT: Force, displacement and acceleration
2) The measured data in the pile and the soil
   strain gauge measurements and pore water transducers.

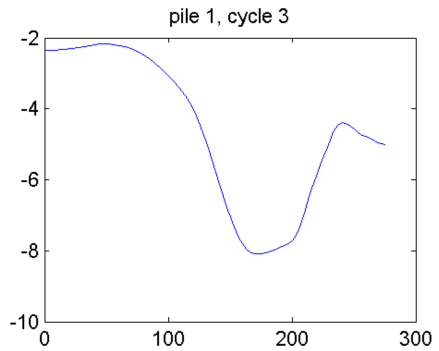
E Results RLT measurements pile head

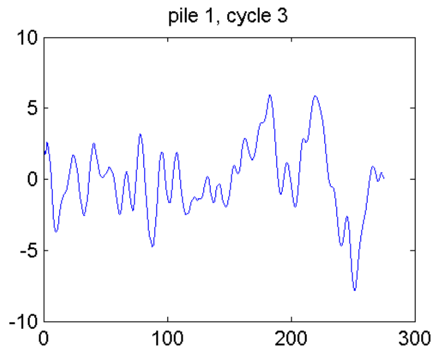
For each load step the following figures are presented:

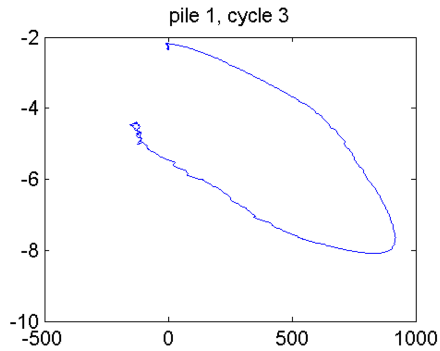
- The load (kN) and the load corrected for inertia (mass*acceleration) (kN) as function on time (ms).
- The displacement (mm) as function on time (ms).
- The acceleration (m/s^2) as function on time (ms).
- The rapid load-displacement diagram (mm-kN). This last graph shows the uncorrected diagram.

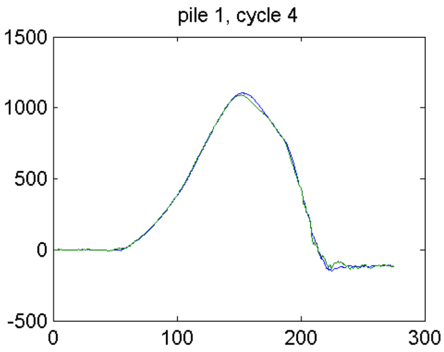

pile 1, cycle 1
1000
800
600
400
200
0
-200
0
100
200
300
pile 1, cycle 1
2
0
-2
-4
-6
0
100
200
300
pile 1, cycle 1
10
5
0
-5
-10
0
100
200
300
pile 1, cycle 1
2
0
-2
-4
-6
-500
0
500
1000
pile 1, cycle 2
1000
800
600
400
200
0
-200
0
100
200
300
pile 1, cycle 2
-1
-2
-3
-4
-5
-6
-7
0
100
200
300
pile 1, cycle 2
10
5
0
-5
-10
0
100
200
300
pile 1, cycle 2
-1
-2
-3
-4
-5
-6
-7
-500
0
500
1000

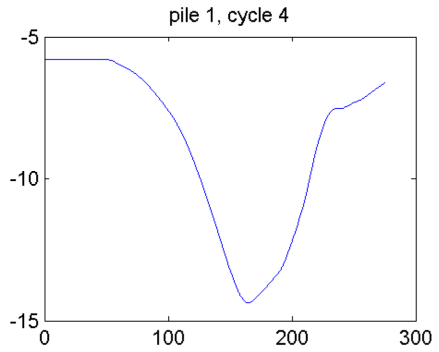

pile 1, cycle 3
1000
800
600
400
200
0
-200
0
100
200
300

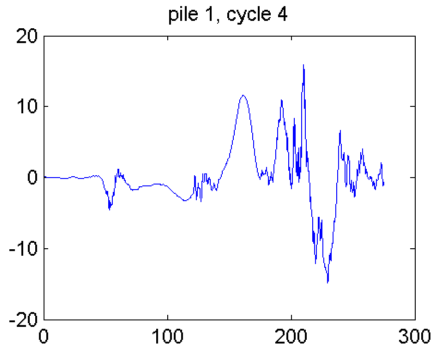

pile 1, cycle 3
-2
-4
-6
-8
-10
0
100
200
300

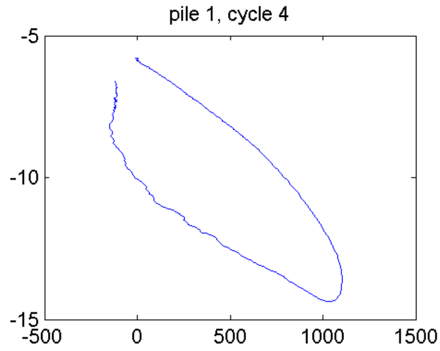

pile 1, cycle 3
10
5
0
-5
-10
0
100
200
300

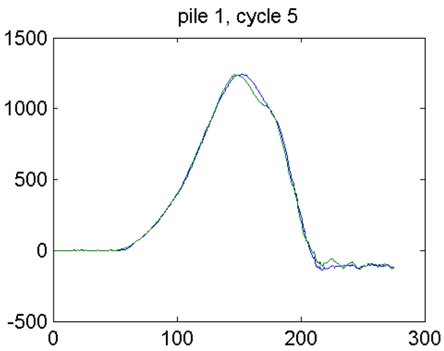

pile 1, cycle 3
-2
-4
-6
-8
-10
-500
0
500
1000

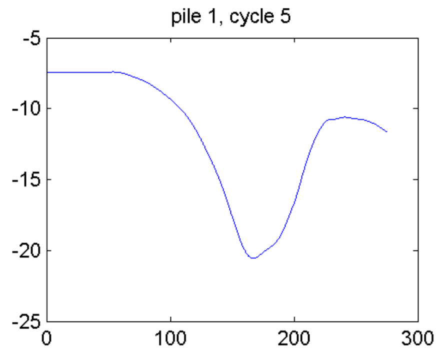

pile 1, cycle 4
1500
1000
500
0
-500
0
100
200
300

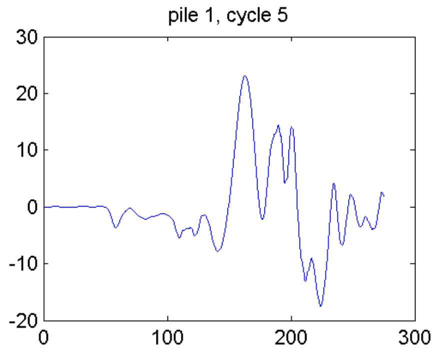

pile 1, cycle 4
-5
-10
-15
0
100
200
300

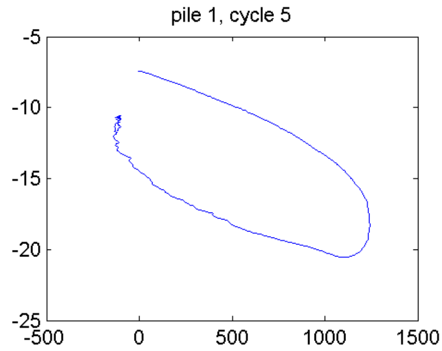

pile 1, cycle 4
20
10
0
-10
-20
0
100
200
300

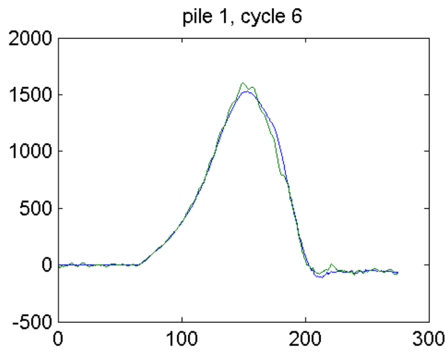

pile 1, cycle 4
-5
-10
-15
-500
0
500
1000
1500

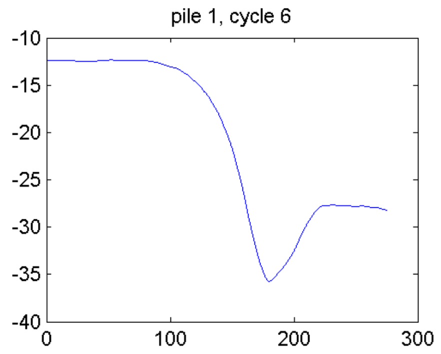

pile 1, cycle 5
1500
1000
500
0
-500
0
100
200
300

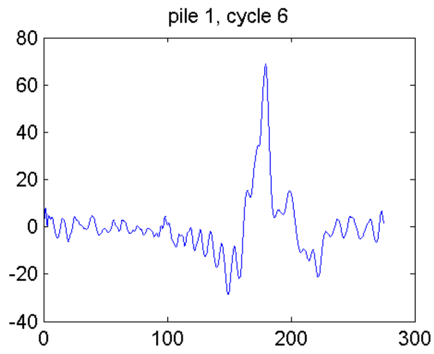

pile 1, cycle 5
-5
-10
-15
-20
-25
0
100
200
300

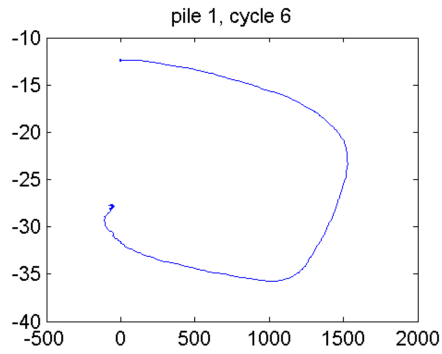

pile 1, cycle 5
30
20
10
0
-10
-20
0
100
200
300

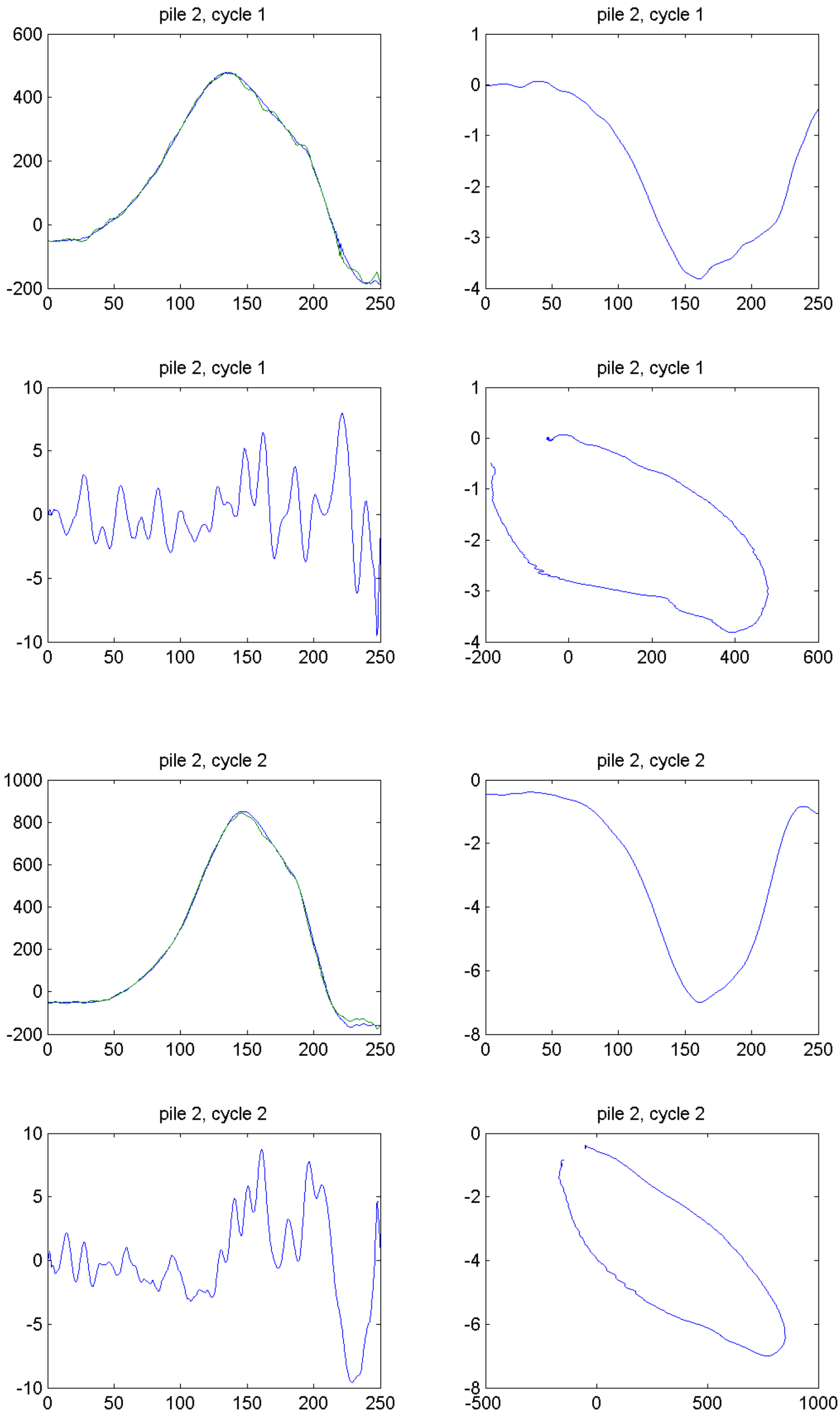

pile 1, cycle 5
-5
-10
-15
-20
-25
-500
0
500
1000
1500

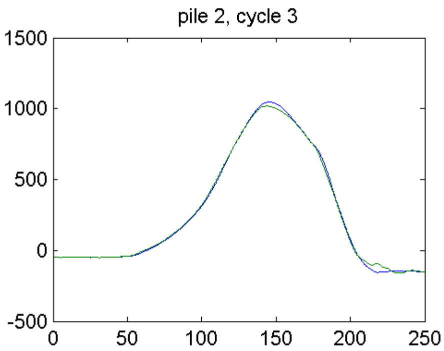

pile 1, cycle 6
2000
1500
1000
500
0
-500
0
100
200
300

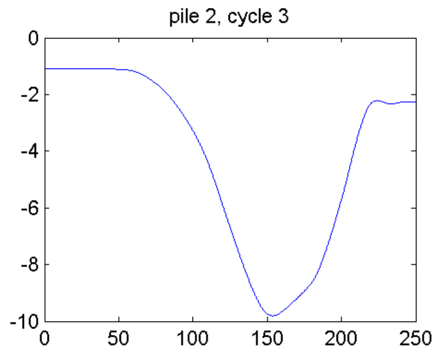

pile 1, cycle 6
-10
-15
-20
-25
-30
-35
-40
0
100
200
300

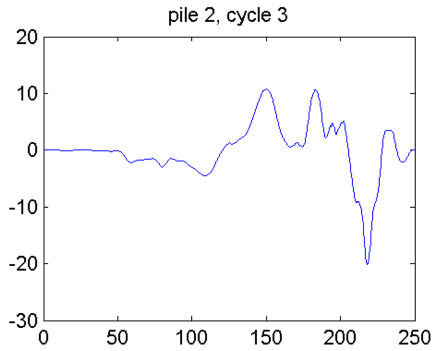

pile 1, cycle 6
80
60
40
20
0
-20
-40
0
100
200
300

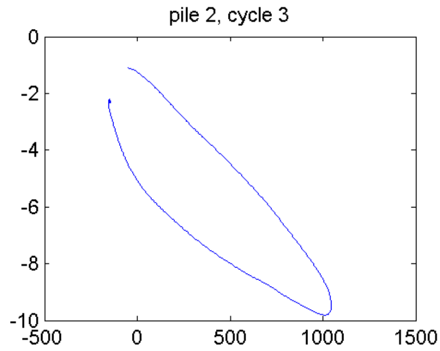

pile 1, cycle 6
-10
-15
-20
-25
-30
-35
-40
-500
0
500
1000
1500
2000

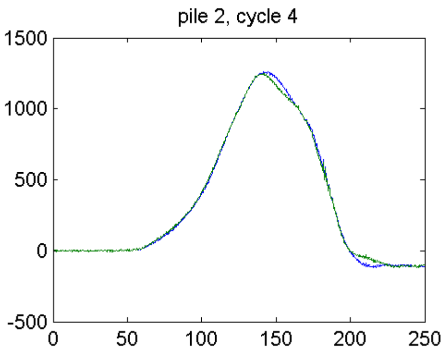

pile 2, cycle 1
pile 2, cycle 1
pile 2, cycle 1
pile 2, cycle 1
pile 2, cycle 2
pile 2, cycle 2
pile 2, cycle 2
pile 2, cycle 2

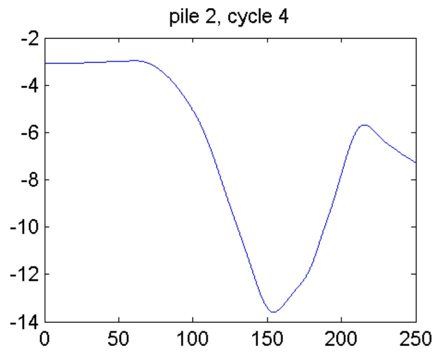

pile 2, cycle 3
1500
1000
500
0
-500
0
50
100
150
200
250

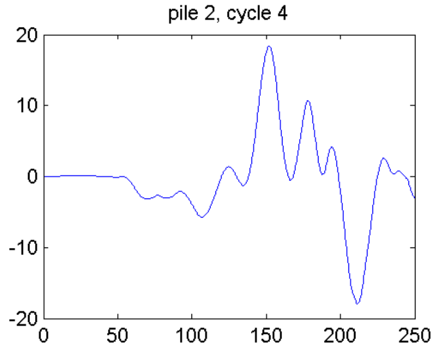

pile 2, cycle 3
0
-2
-4
-6
-8
-10
0
50
100
150
200
250

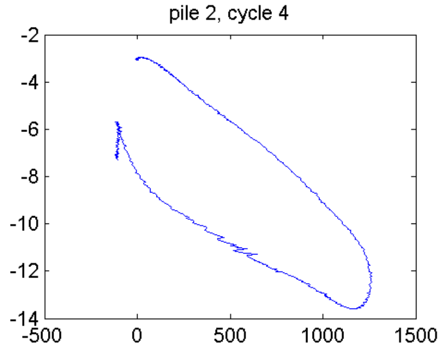

pile 2, cycle 3
20
10
0
-10
-20
-30
0
50
100
150
200
250


pile 2, cycle 3
0
-2
-4
-6
-8
-10
-500
0
500
1000
1500


pile 2, cycle 4
1500
1000
500
0
-500
0
50
100
150
200
250

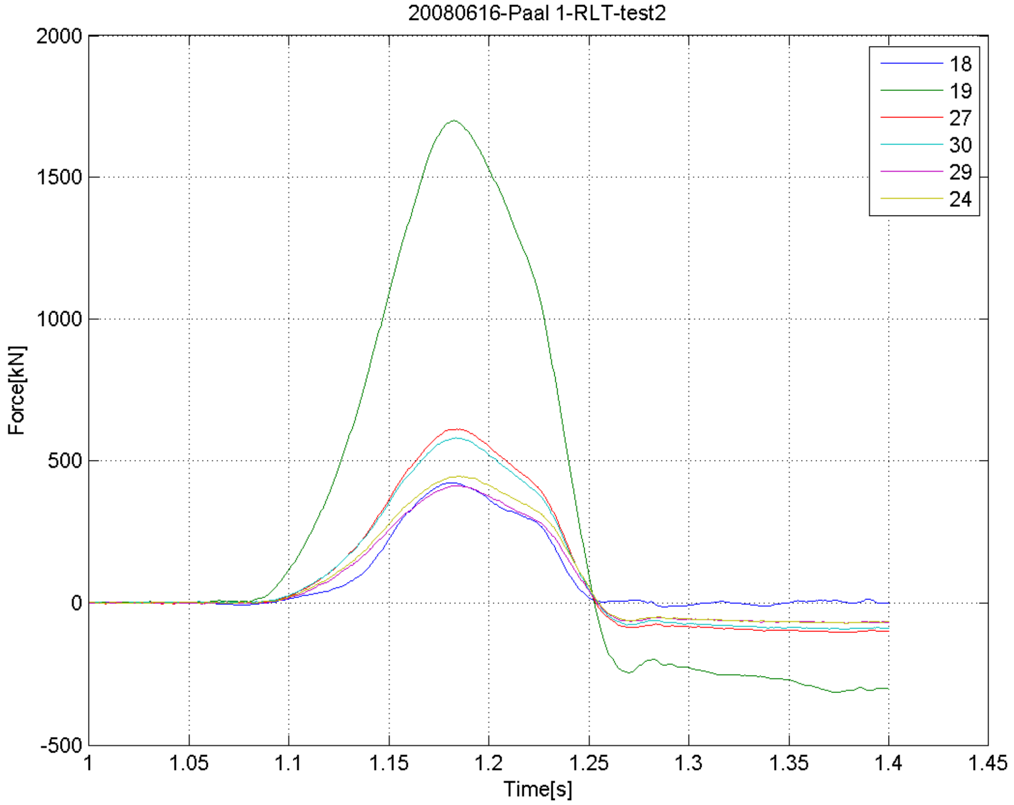

pile 2, cycle 4
-2
-4
-6
-8
-10
-12
-14
0
50
100
150
200
250

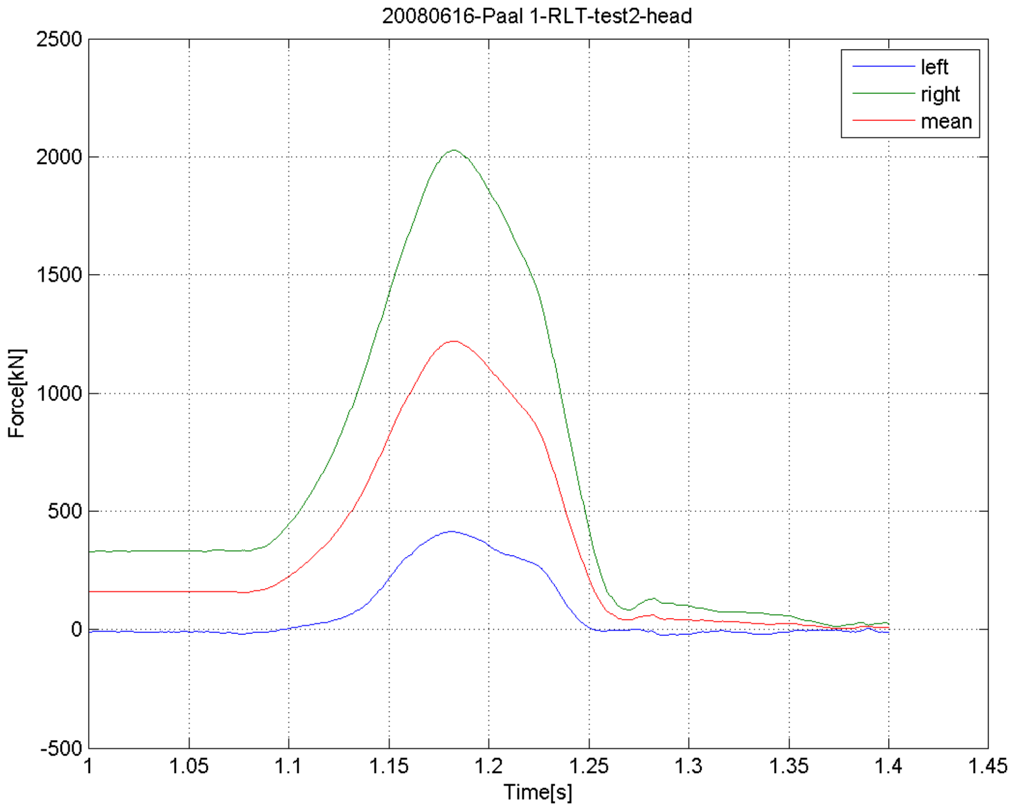

pile 2, cycle 4
20
10
0
-10
-20
0
50
100
150
200
250

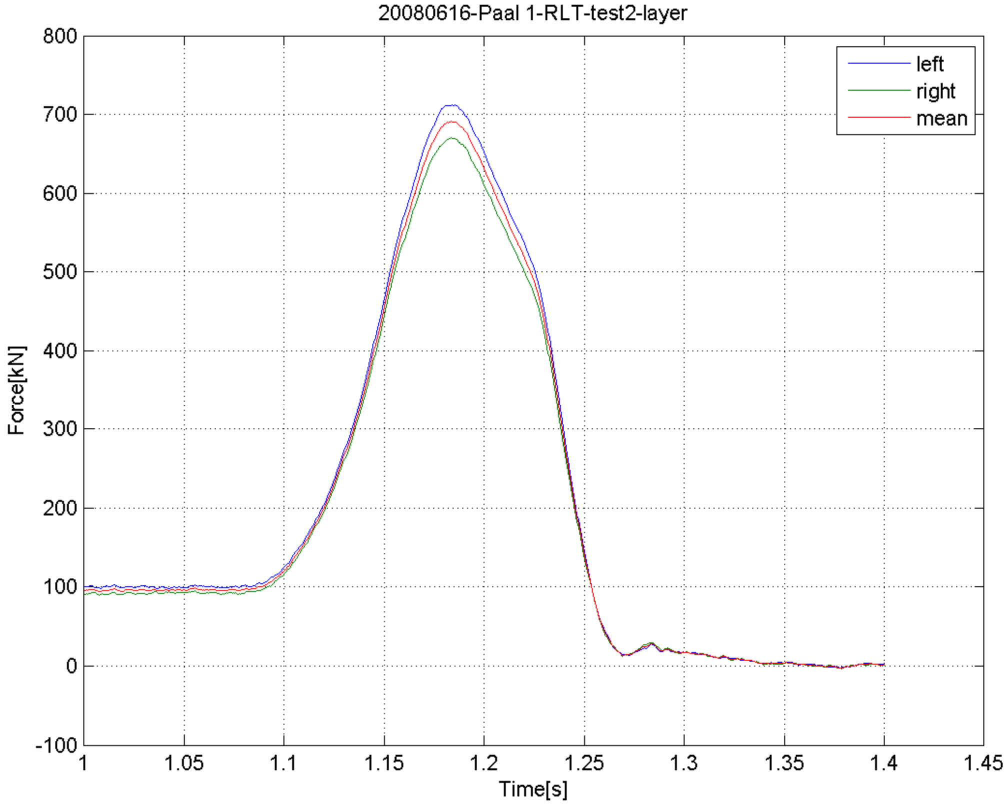

pile 2, cycle 4
-2
-4
-6
-8
-10
-12
-14
-500
0
500
1000
1500

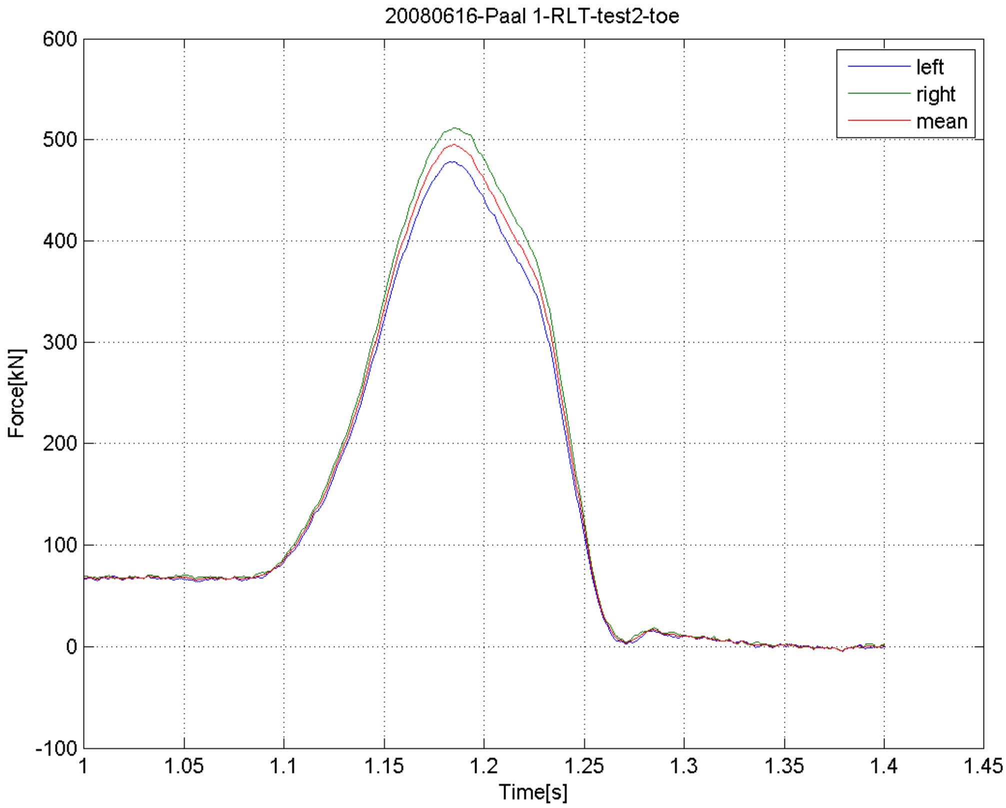
F Results of strain measurements during RLT

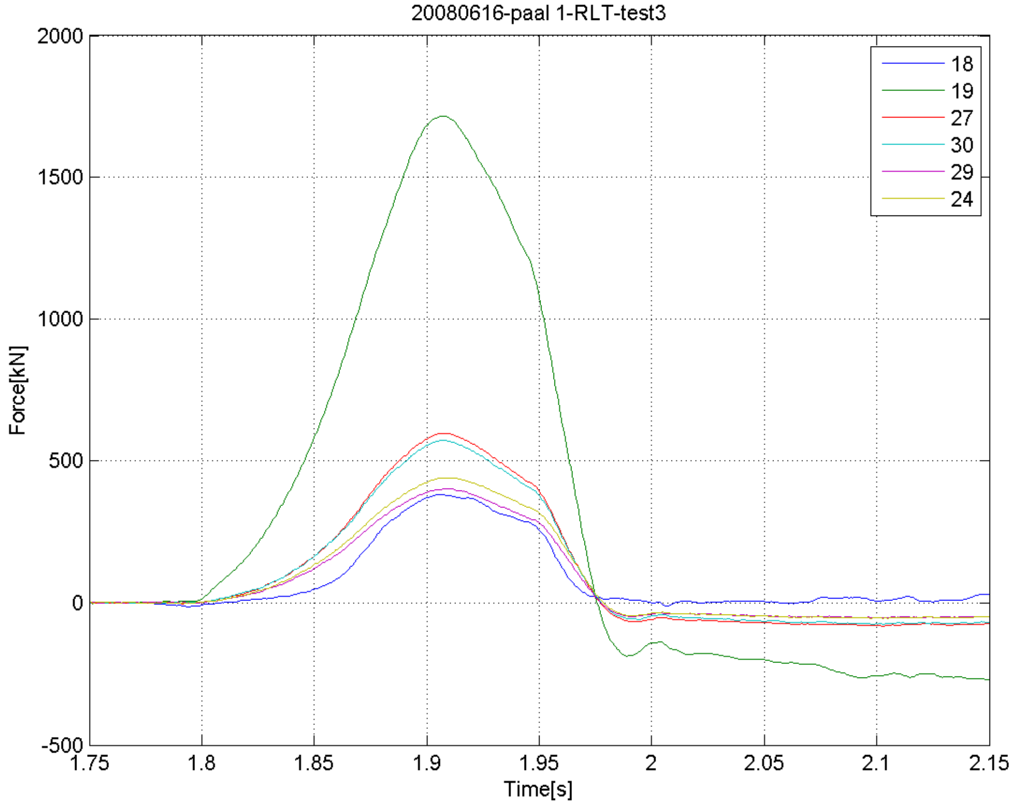
F.1 Pile 1

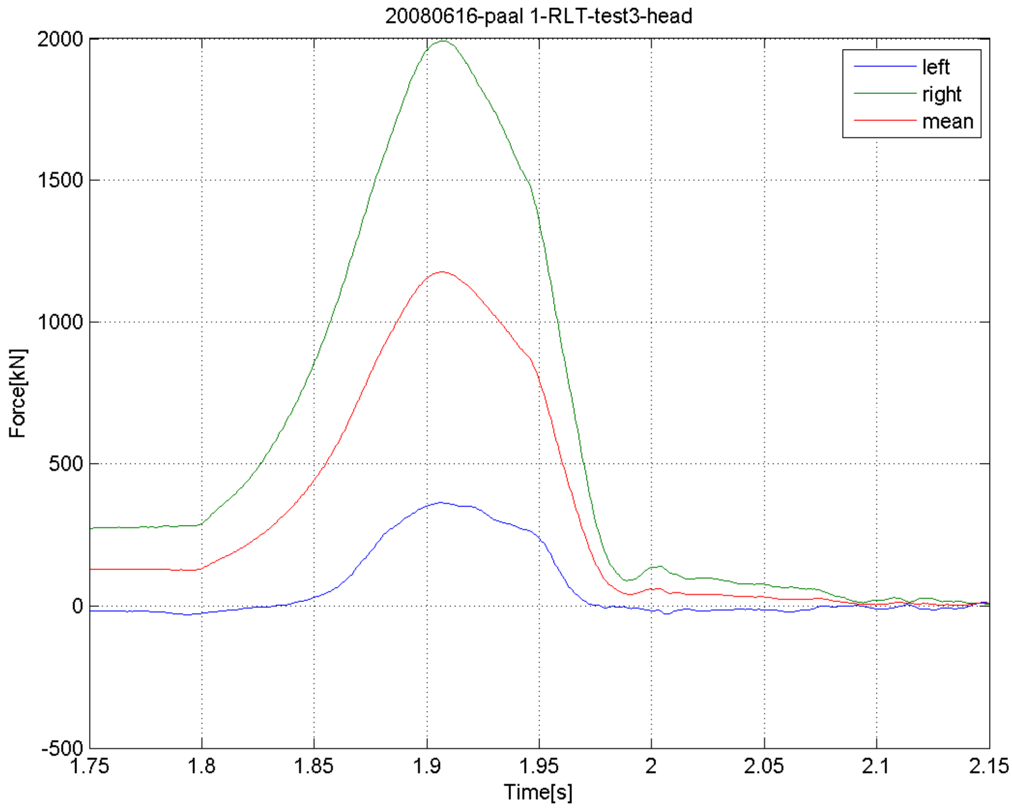

20080616-Paal 1-RLT-test2
Force[kN]
Time[s]
18
19
27
30
29
24

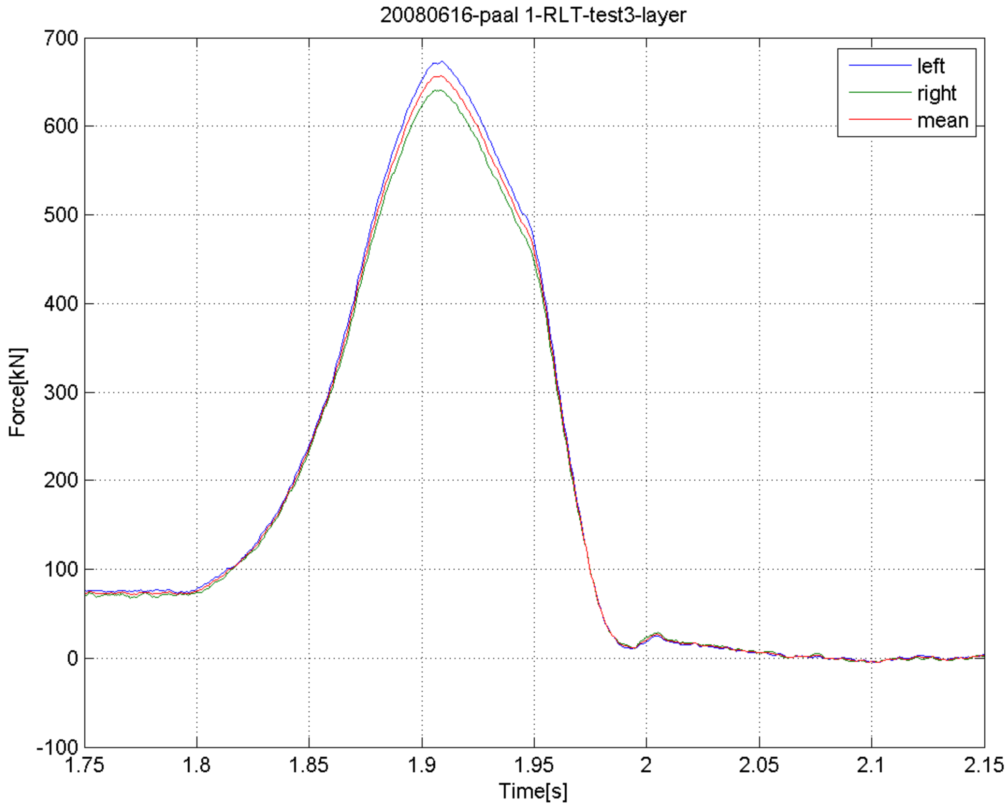

20080616-Paal 1-RLT-test2-head
Force[kN]
Time[s]
left
right
mean


20080616-Paal 1-RLT-test2-layer
left
right
mean
Force[kN]
Time[s]
800
700
600
500
400
300
200
100
0
-100
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45

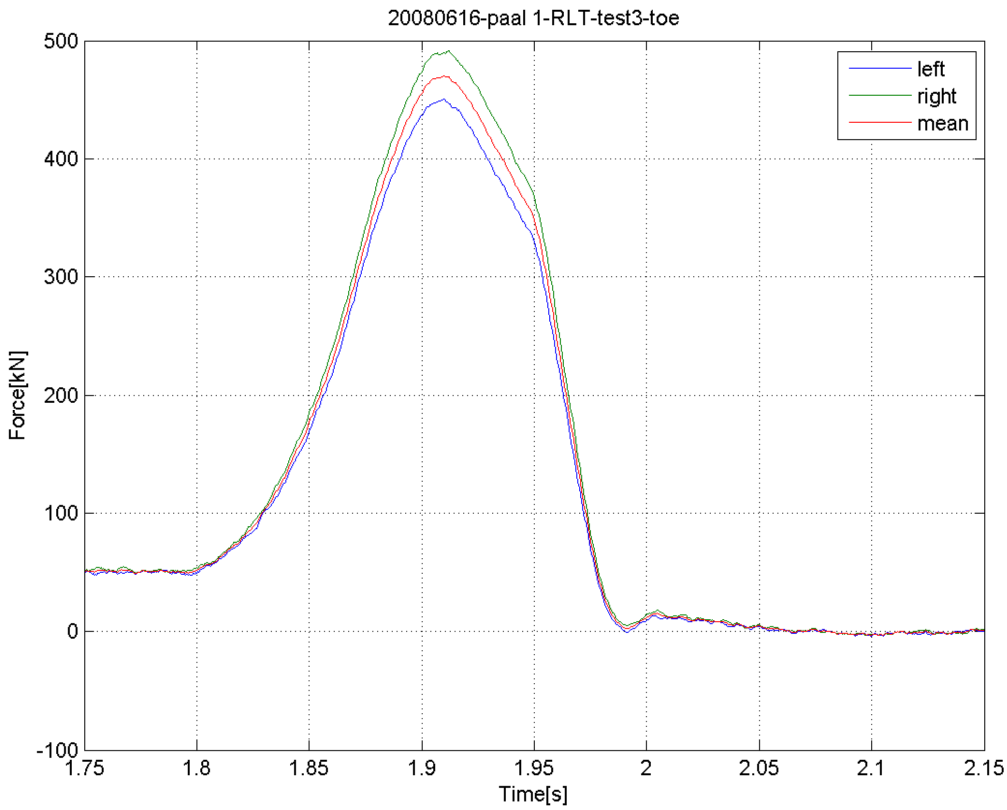

20080616-Paal 1-RLT-test2-toe
left
right
mean
Force[kN]
Time[s]
600
500
400
300
200
100
0
-100
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45


20080616-paal 1-RLT-test3
Force[kN]
Time[s]
2000
1500
1000
500
0
-500
1.75
1.8
1.85
1.9
1.95
2
2.05
2.1
2.15
18
19
27
30
29
24

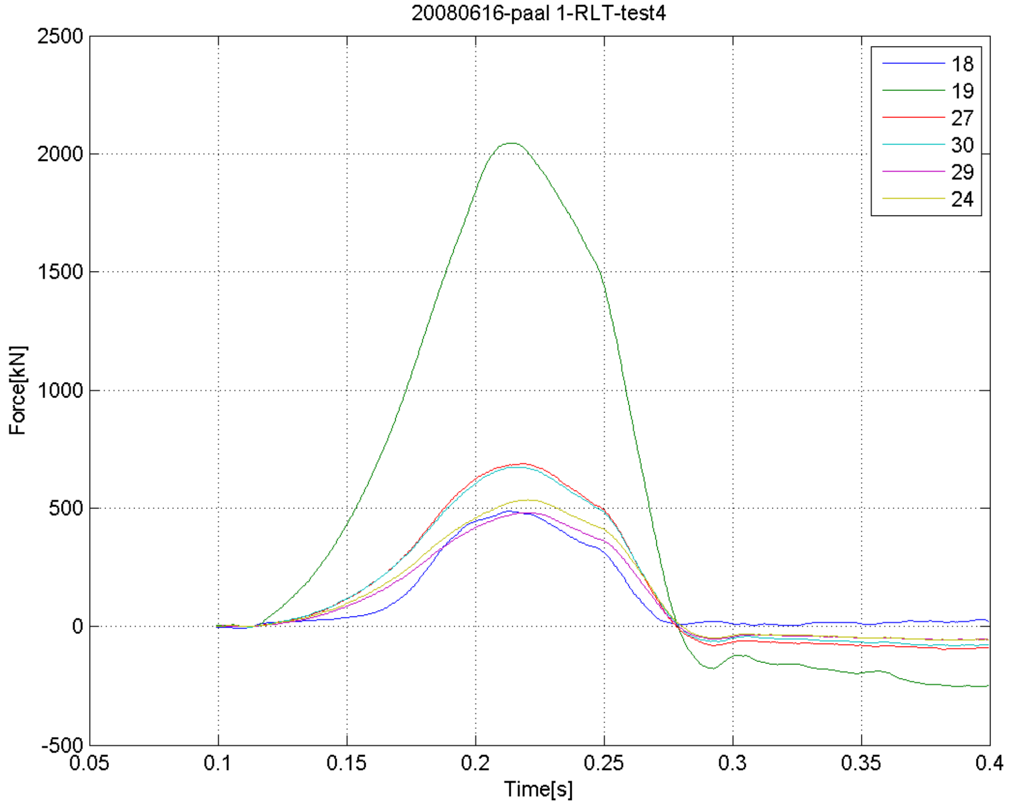

20080616-paal 1-RLT-test3-head
Force[kN]
Time[s]
2000
1500
1000
500
0
-500
1.75
1.8
1.85
1.9
1.95
2
2.05
2.1
2.15
left
right
mean

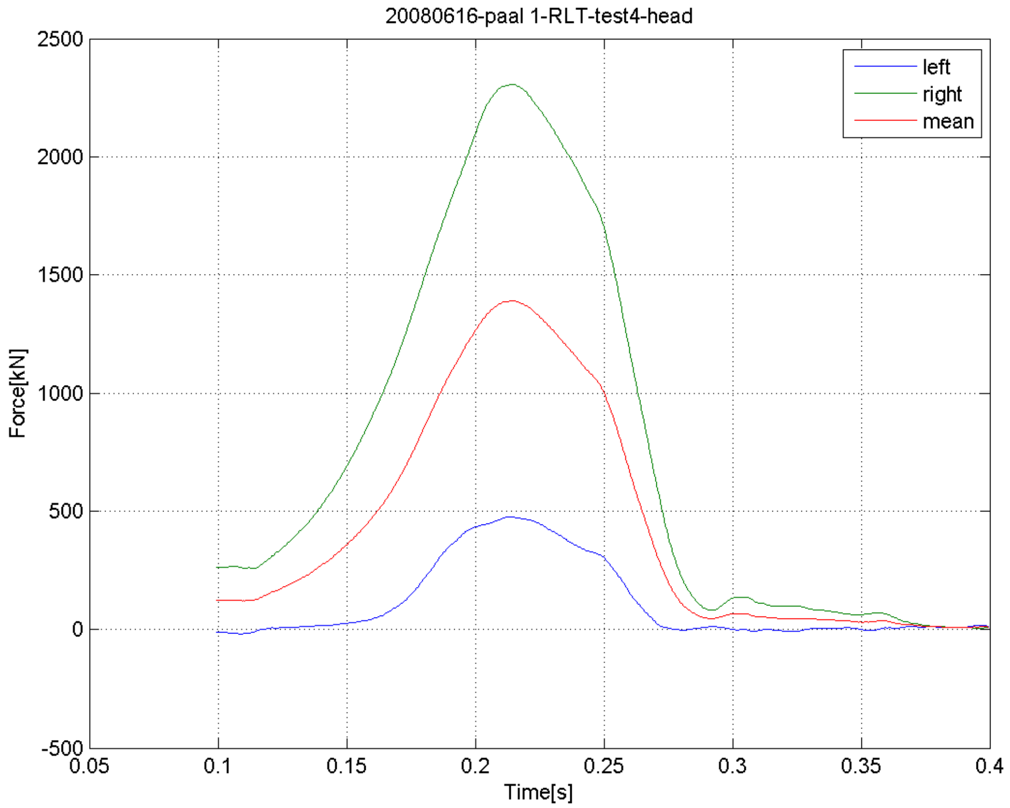


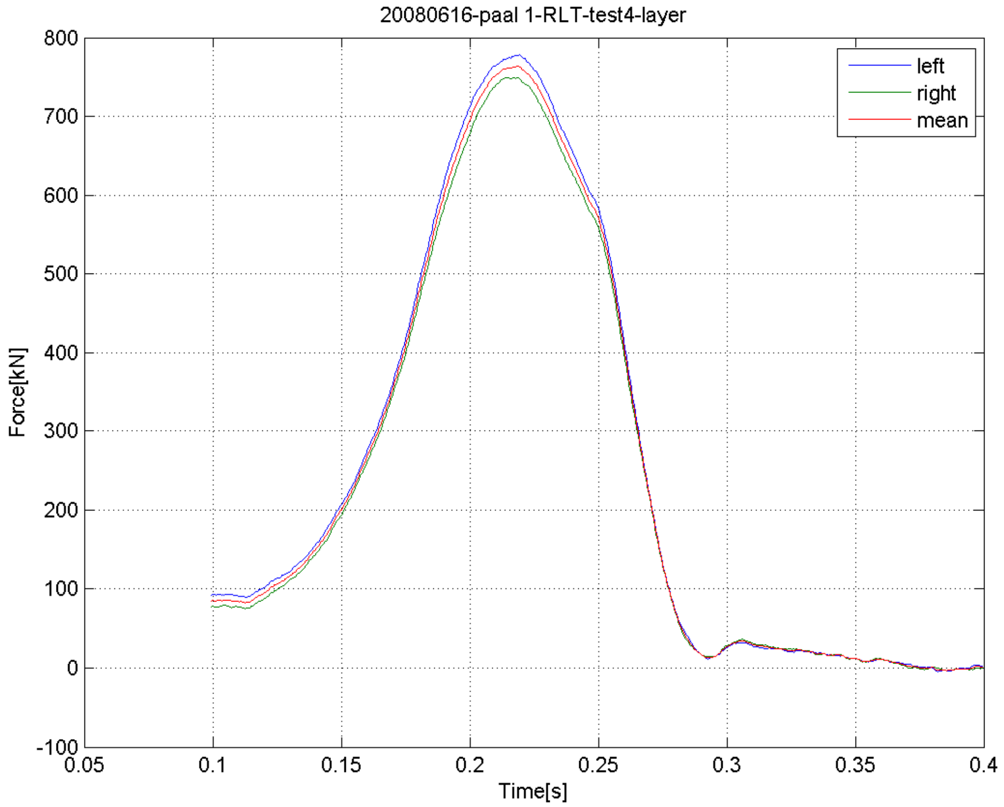
20080616-paal 1-RLT-test3-layer
left
right
mean
Force[kN]
Time[s]
700
600
500
400
300
200
100
0
-100
1.75
1.8
1.85
1.9
1.95
2
2.05
2.1
2.15

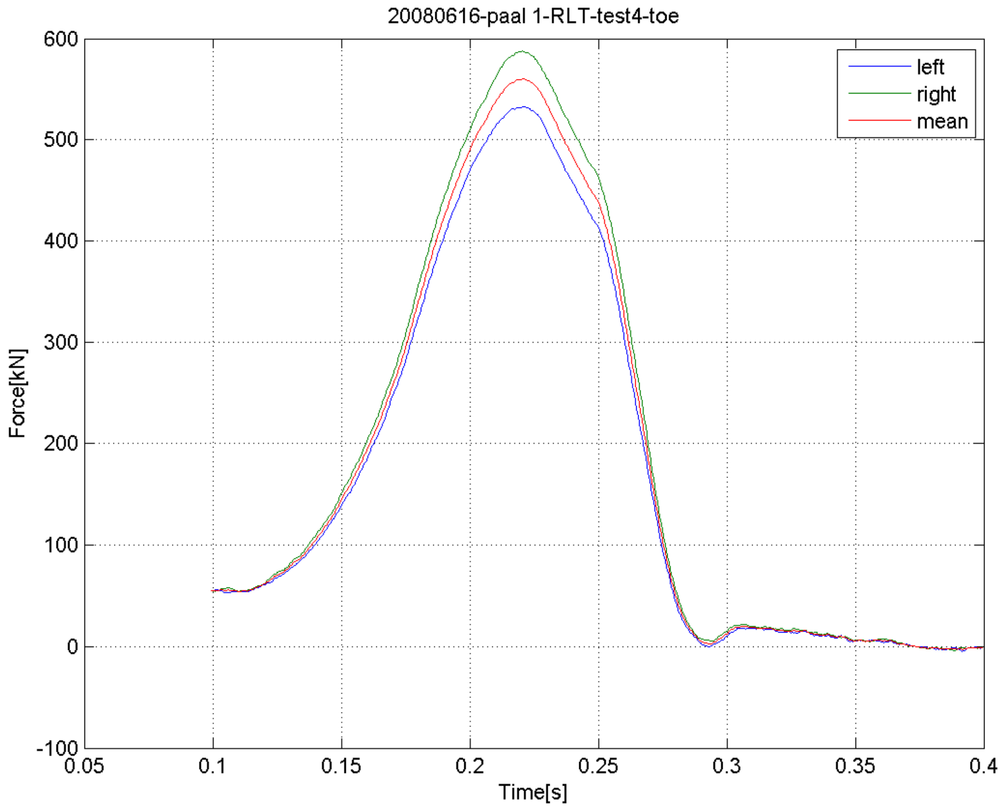


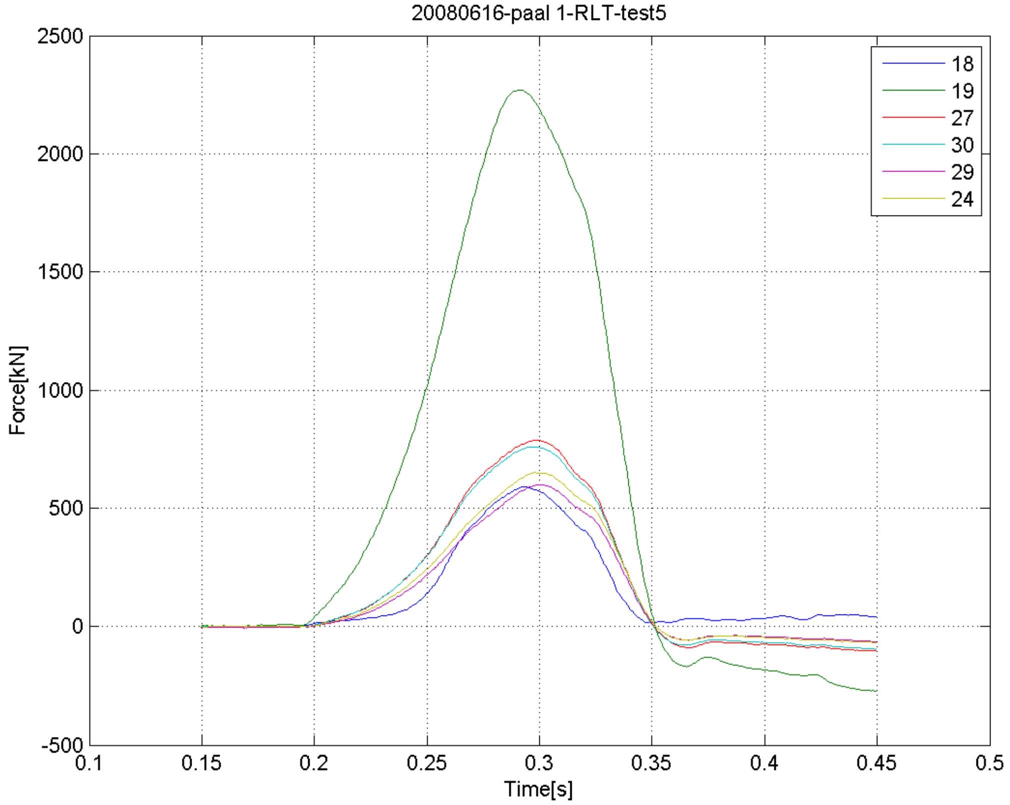
20080616-paal 1-RLT-test3-toe
left
right
mean
Force[kN]
Time[s]
500
400
300
200
100
0
-100
1.75
1.8
1.85
1.9
1.95
2
2.05
2.1
2.15

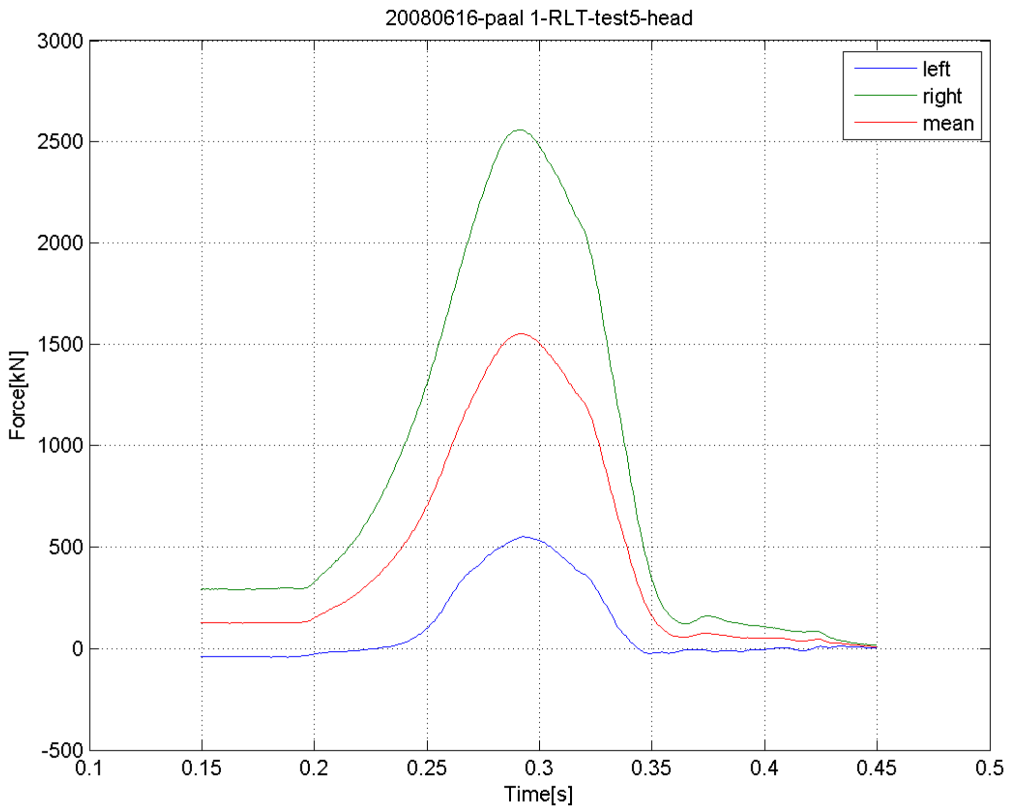

20080616-paal 1-RLT-test4
Force[kN]
Time[s]
18
19
27
30
29
24
2500
2000
1500
1000
500
0
-500
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

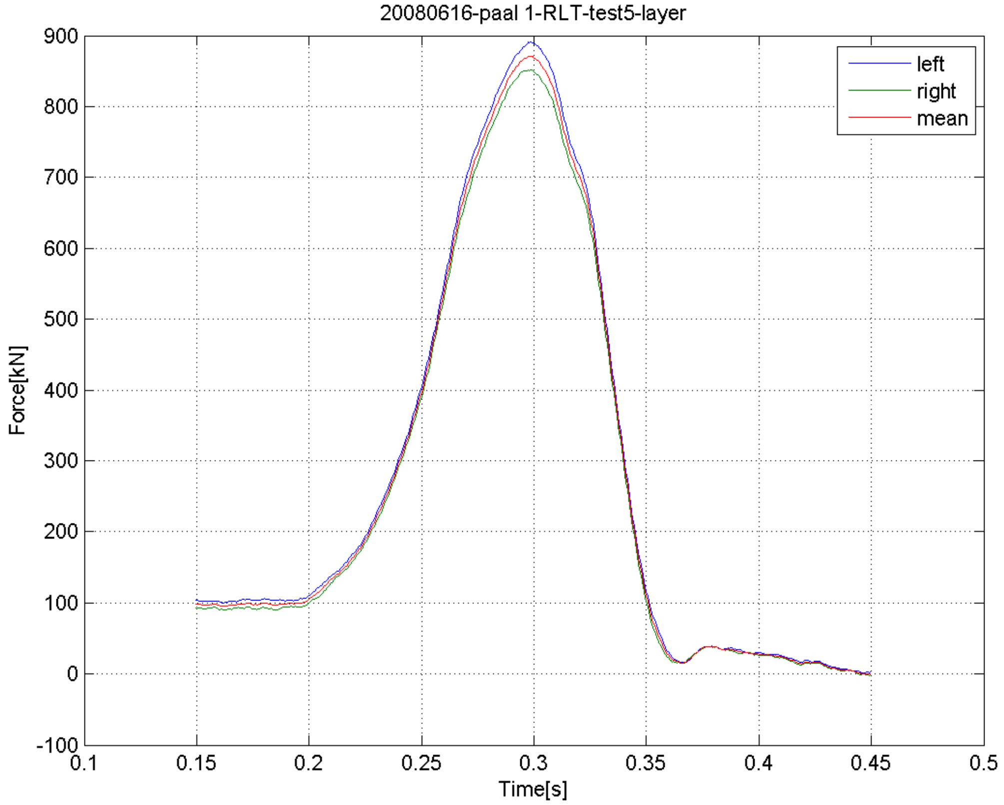

20080616-paal 1-RLT-test4-head
Force[kN]
Time[s]
left
right
mean
2500
2000
1500
1000
500
0
-500
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

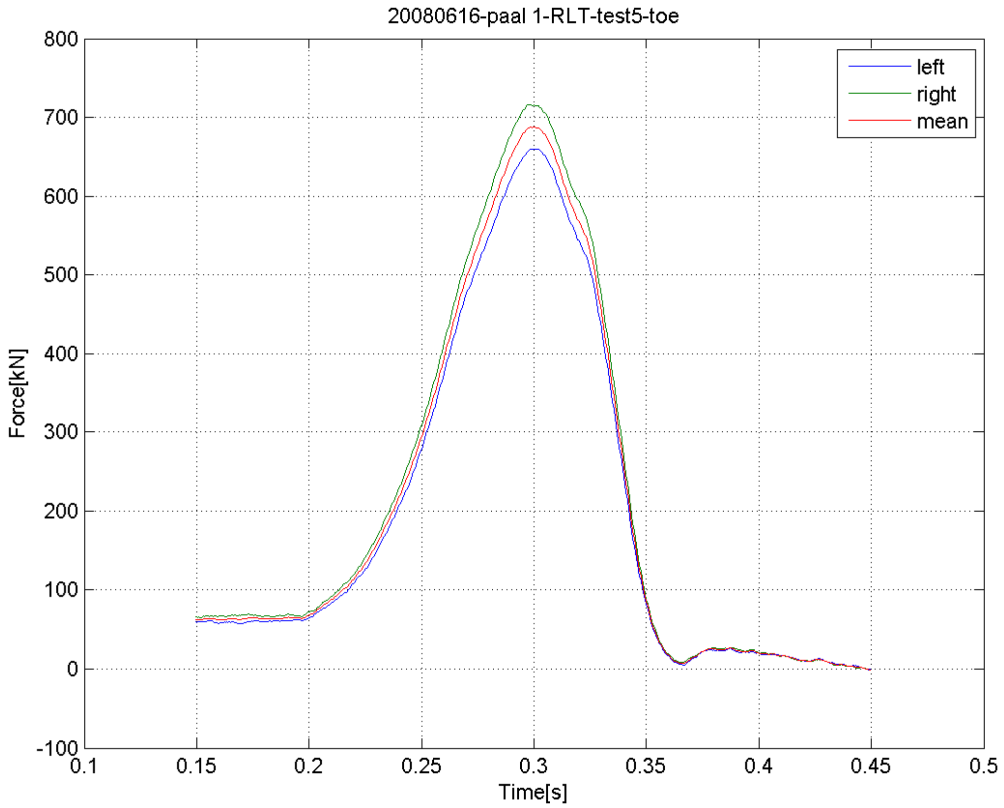

20080616-paal 1-RLT-test4-layer
Force[kN]
Time[s]
left
right
mean
800
700
600
500
400
300
200
100
0
-100
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

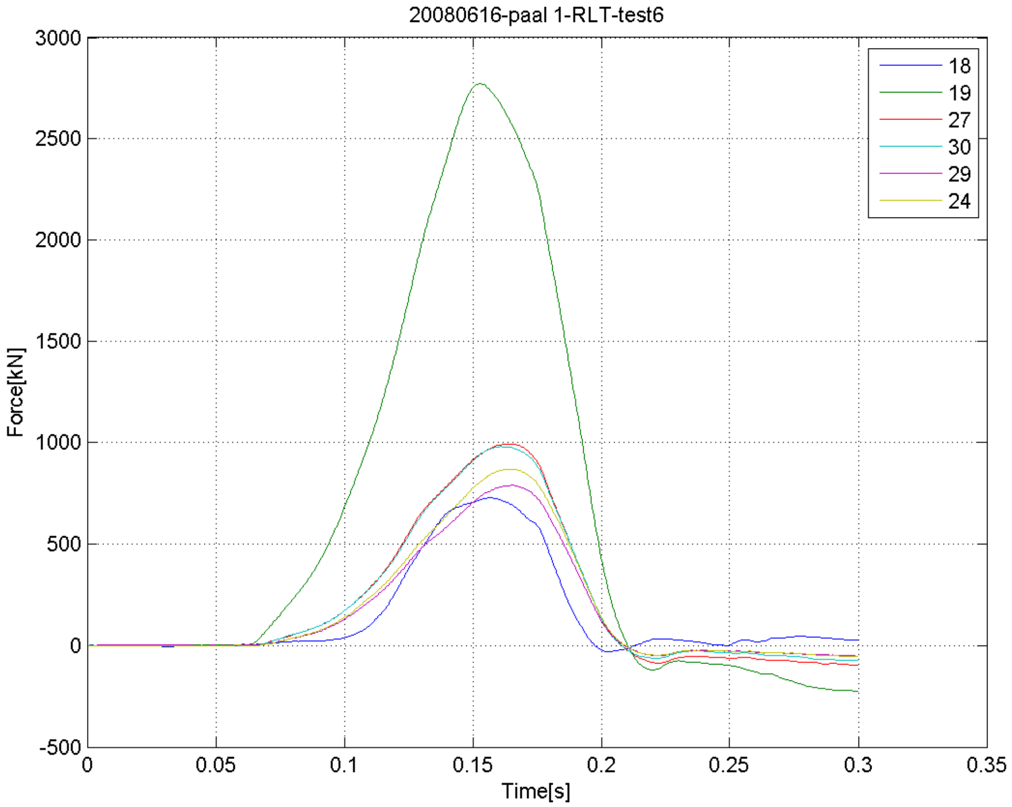

20080616-paal 1-RLT-test4-toe
Force[kN]
Time[s]
left
right
mean
600
500
400
300
200
100
0
-100
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

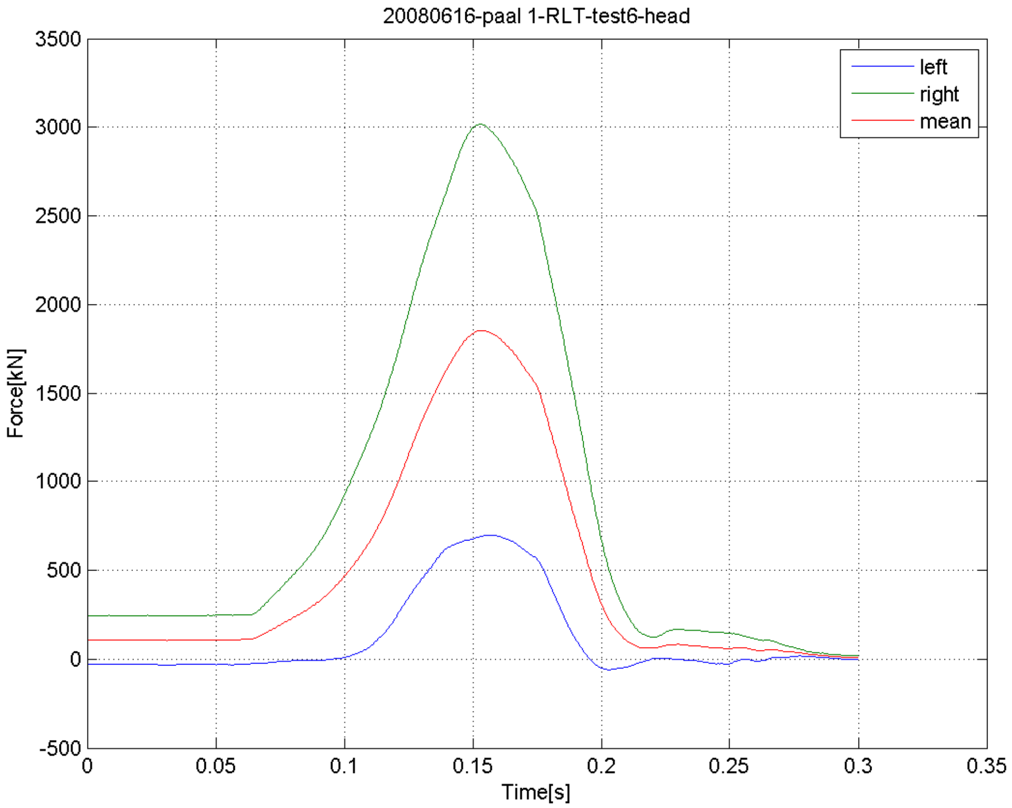

20080616-paal 1-RLT-test5
Force[kN]
Time[s]
18
19
27
30
29
24
2500
2000
1500
1000
500
0
-500
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

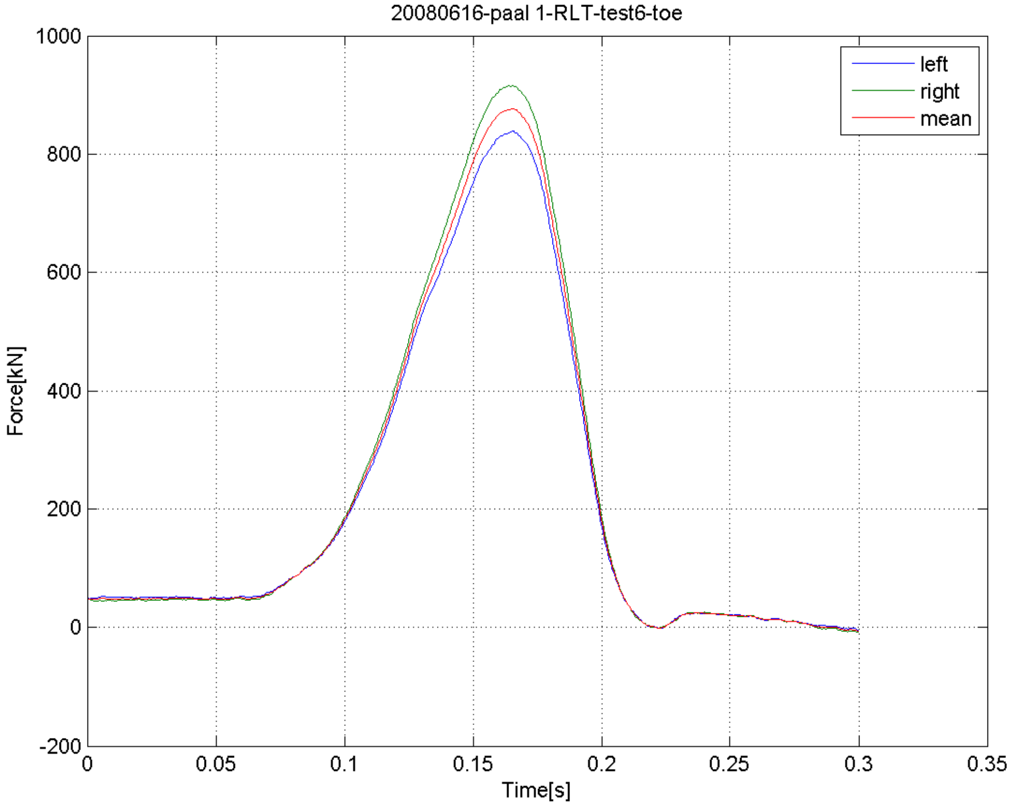

20080616-paal 1-RLT-test5-head
Force[kN]
Time[s]
left
right
mean
3000
2500
2000
1500
1000
500
0
-500
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


20080616-paal 1-RLT-test5-layer
Force[kN]
Time[s]
left
right
mean
900
800
700
600
500
400
300
200
100
0
-100
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

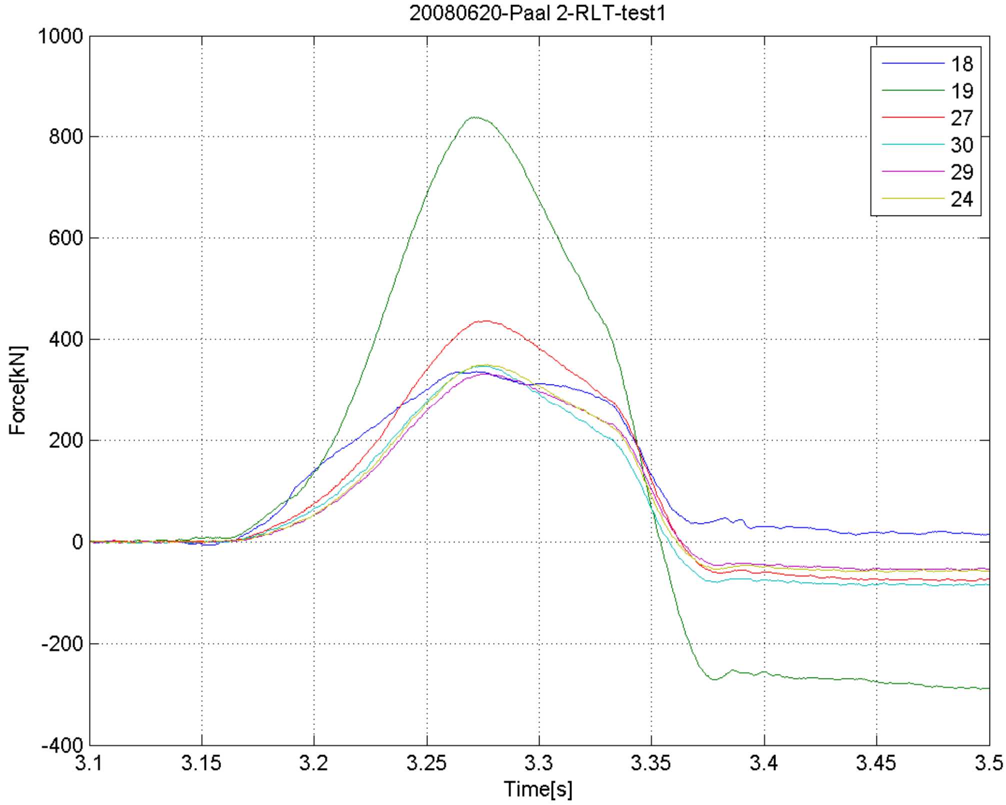

20080616-paal 1-RLT-test5-toe
Force[kN]
Time[s]
left
right
mean
800
700
600
500
400
300
200
100
0
-100
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

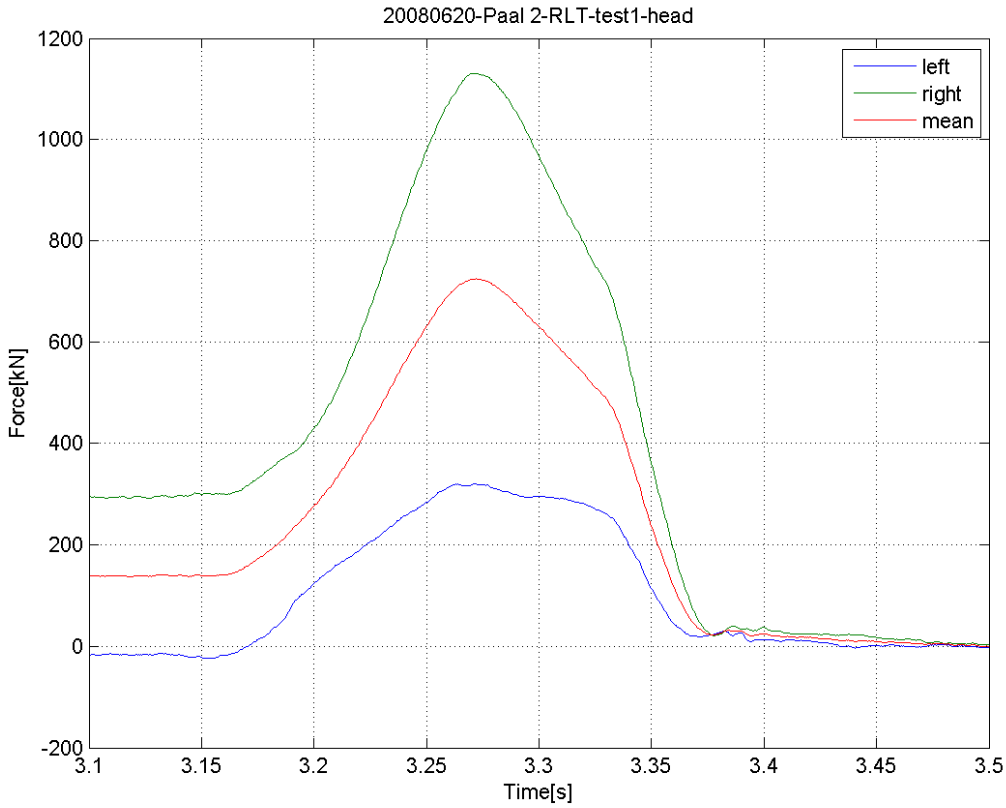

20080616-paal 1-RLT-test6
Force[kN]
Time[s]
3000
2500
2000
1500
1000
500
0
-500
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
18
19
27
30
29
24

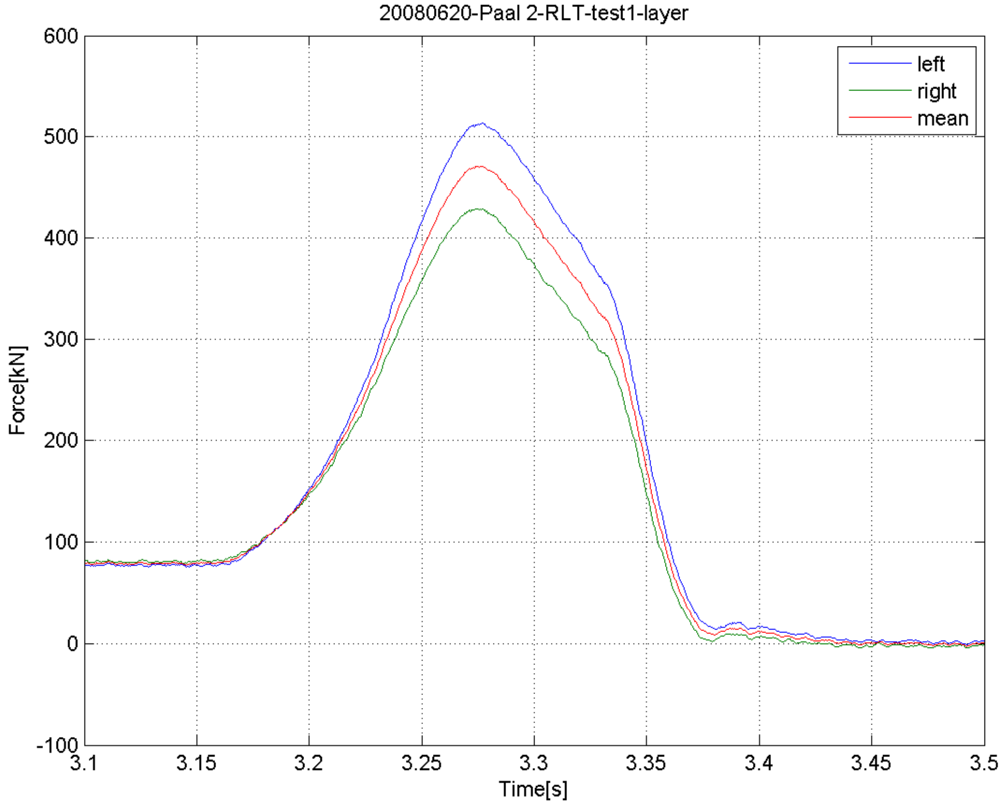

20080616-paal 1-RLT-test6-head
Force[kN]
Time[s]
3500
3000
2500
2000
1500
1000
500
0
-500
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
left
right
mean

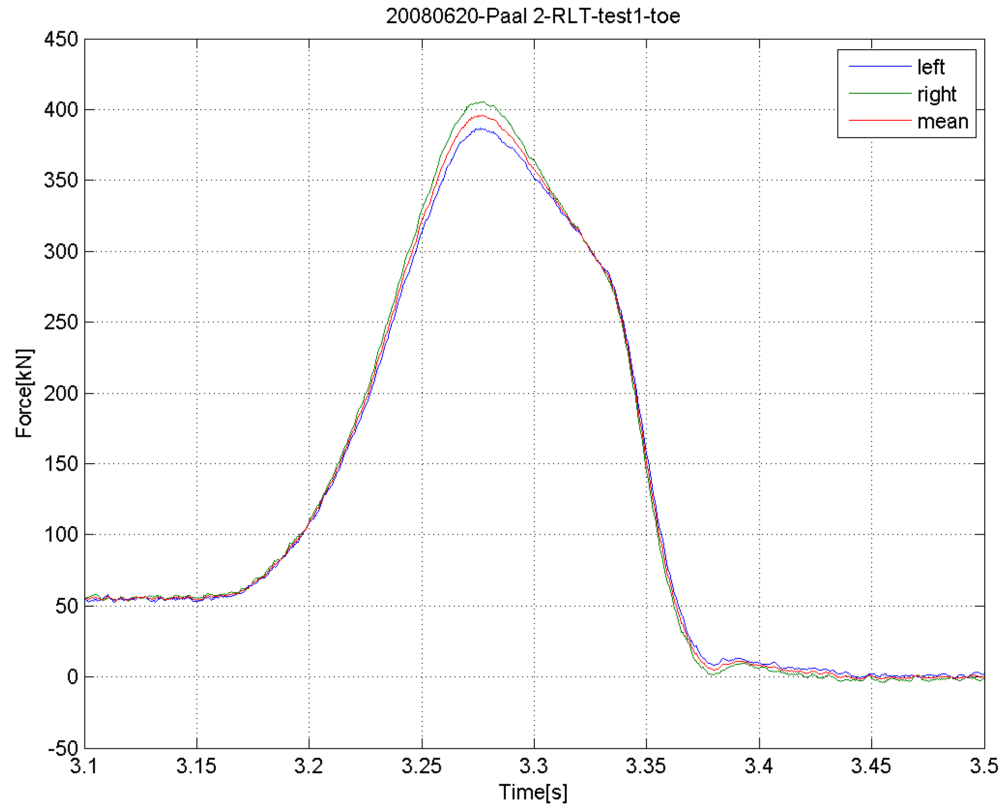

20080616-paal 1-RLT-test6-toe
Force[kN]
Time[s]
left
right
mean
1000
800
600
400
200
0
-200
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

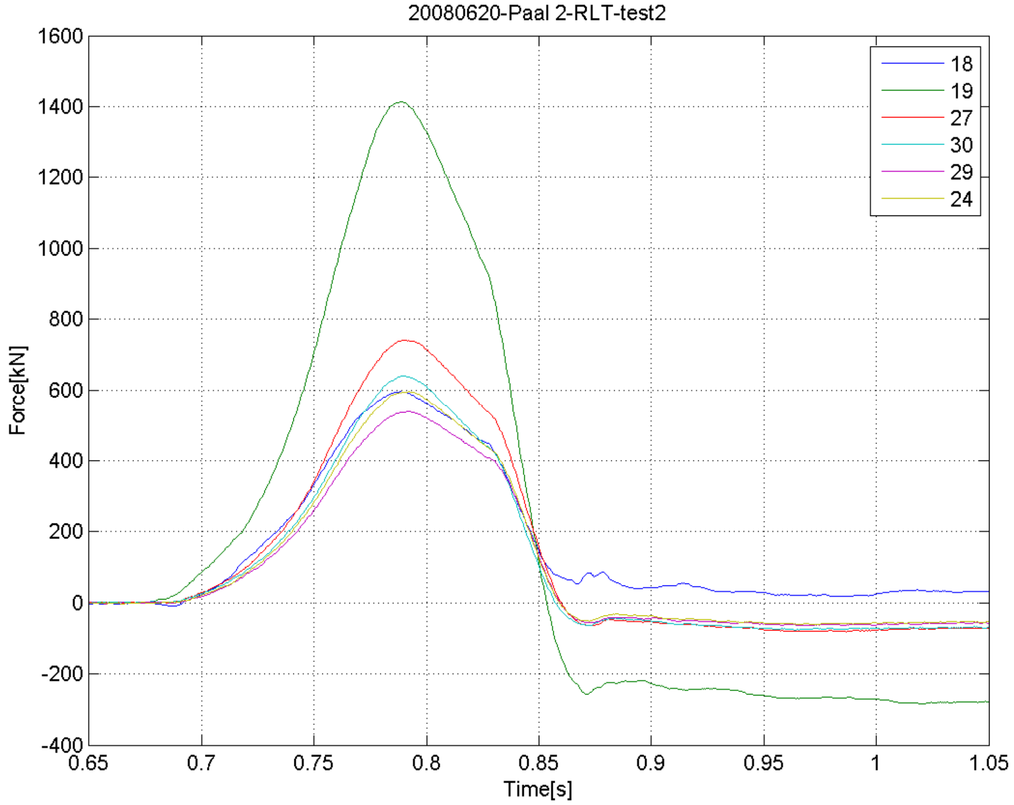
F.2 Pile 2

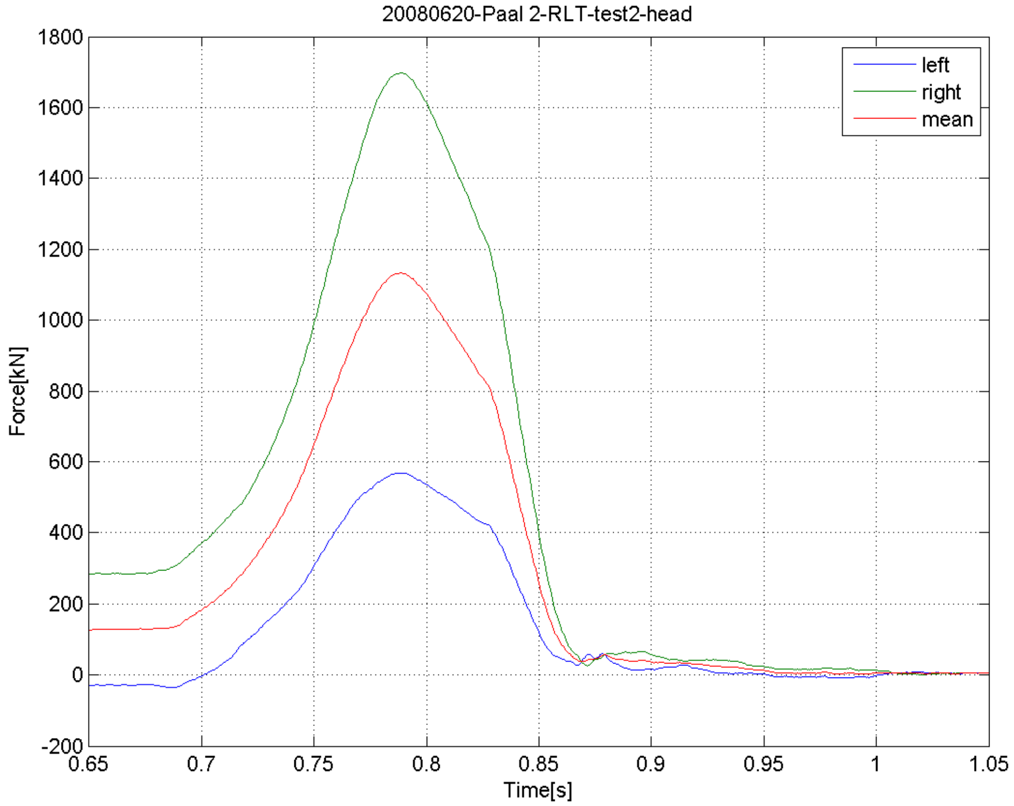

20080620-Paal 2-RLT-test1
Force[kN]
Time[s]
18
19
27
30
29
24
1000
800
600
400
200
0
-200
-400
3.1
3.15
3.2
3.25
3.3
3.35
3.4
3.45
3.5

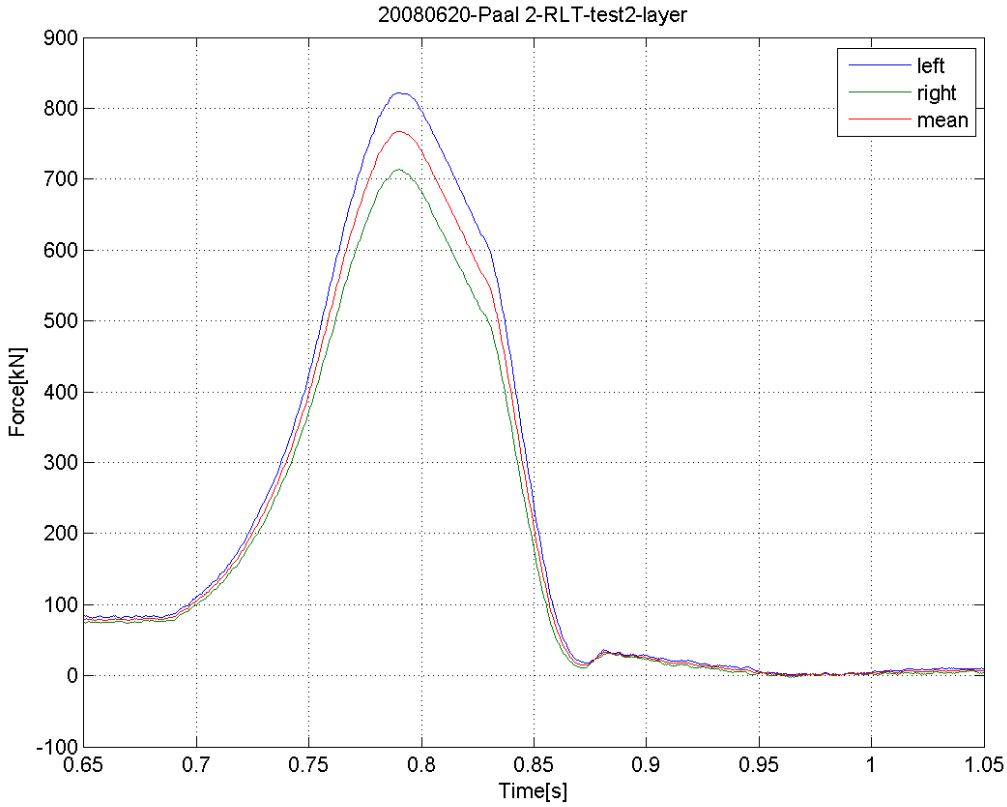

20080620-Paal 2-RLT-test1-head
Force[kN]
Time[s]
left
right
mean
1200
1000
800
600
400
200
0
-200
3.1
3.15
3.2
3.25
3.3
3.35
3.4
3.45
3.5

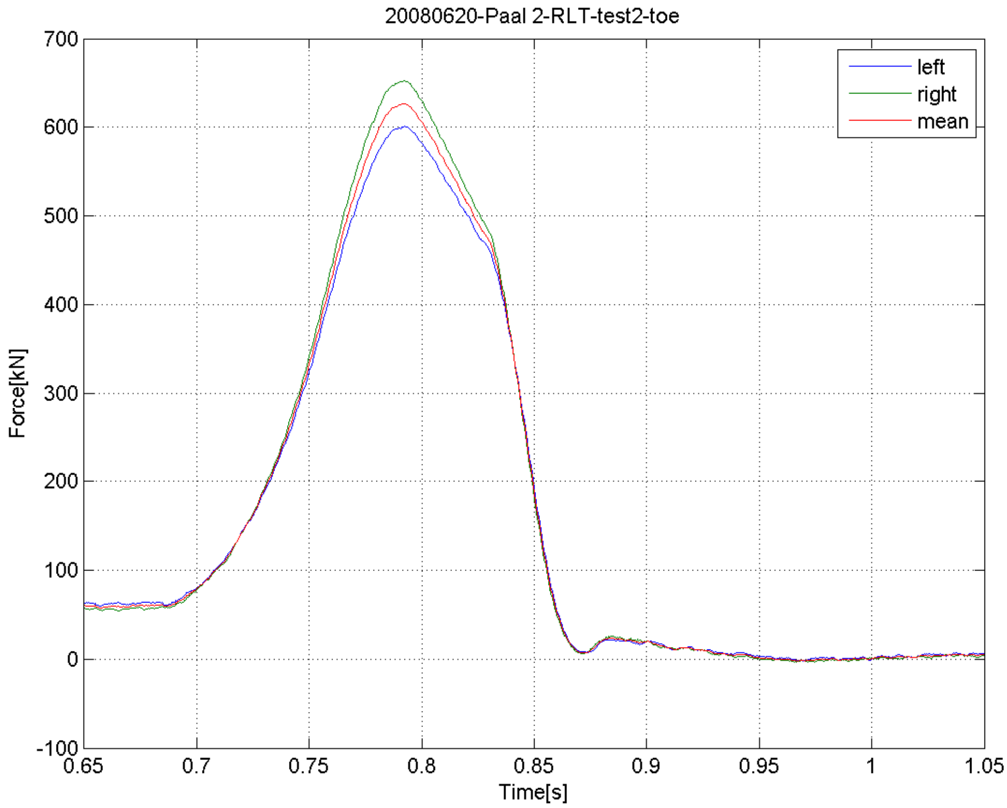

20080620-Paal 2-RLT-test1-layer
Force[kN]
Time[s]
left
right
mean
600
500
400
300
200
100
0
-100
3.1
3.15
3.2
3.25
3.3
3.35
3.4
3.45
3.5

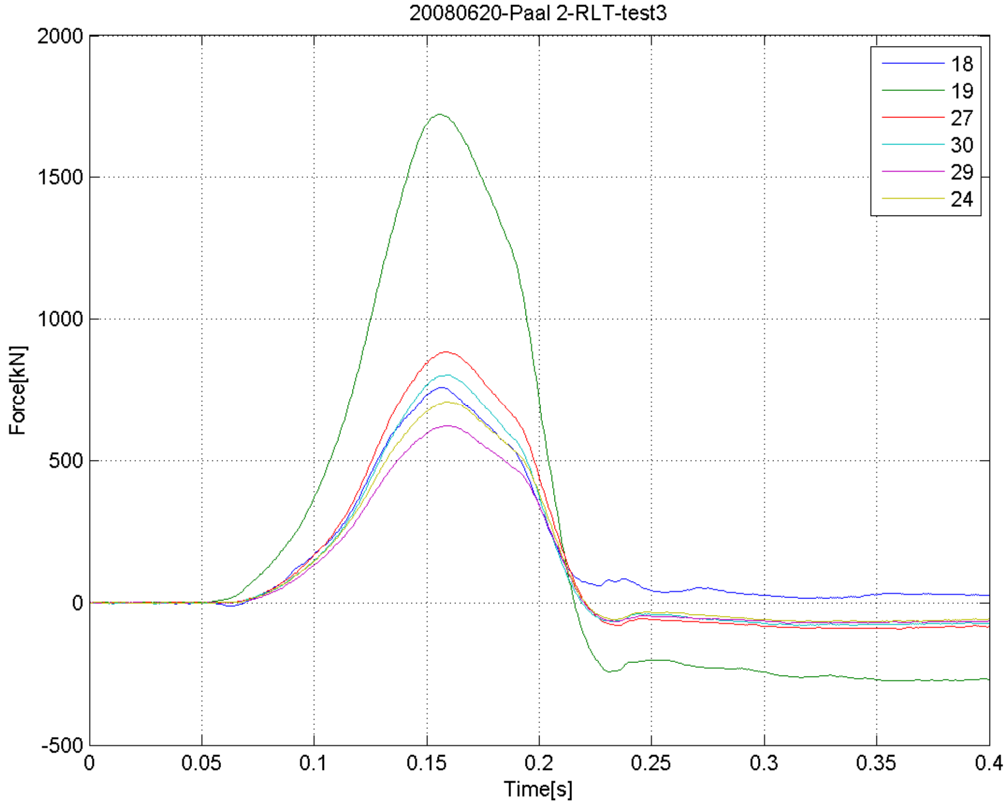

20080620-Paal 2-RLT-test1-toe
Force[kN]
Time[s]
left
right
mean
450
400
350
300
250
200
150
100
50
0
-50
3.1
3.15
3.2
3.25
3.3
3.35
3.4
3.45
3.5

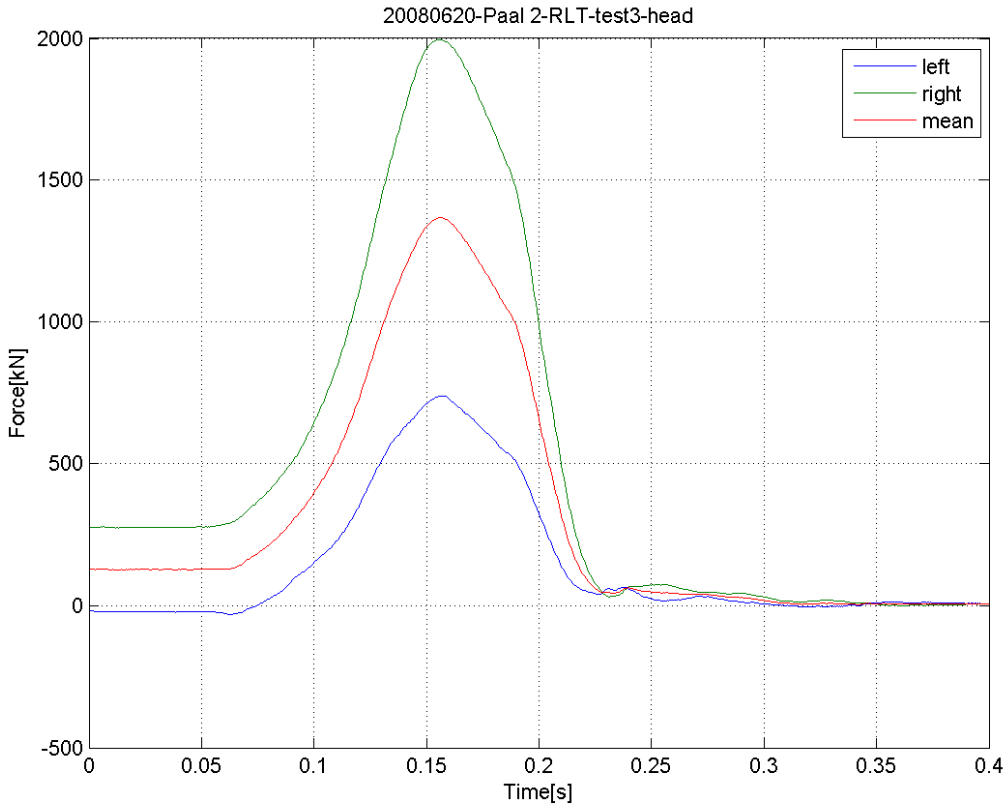

20080620-Paal 2-RLT-test2
Force[kN]
Time[s]
18
19
27
30
29
24
1600
1400
1200
1000
800
600
400
200
0
-200
-400
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05

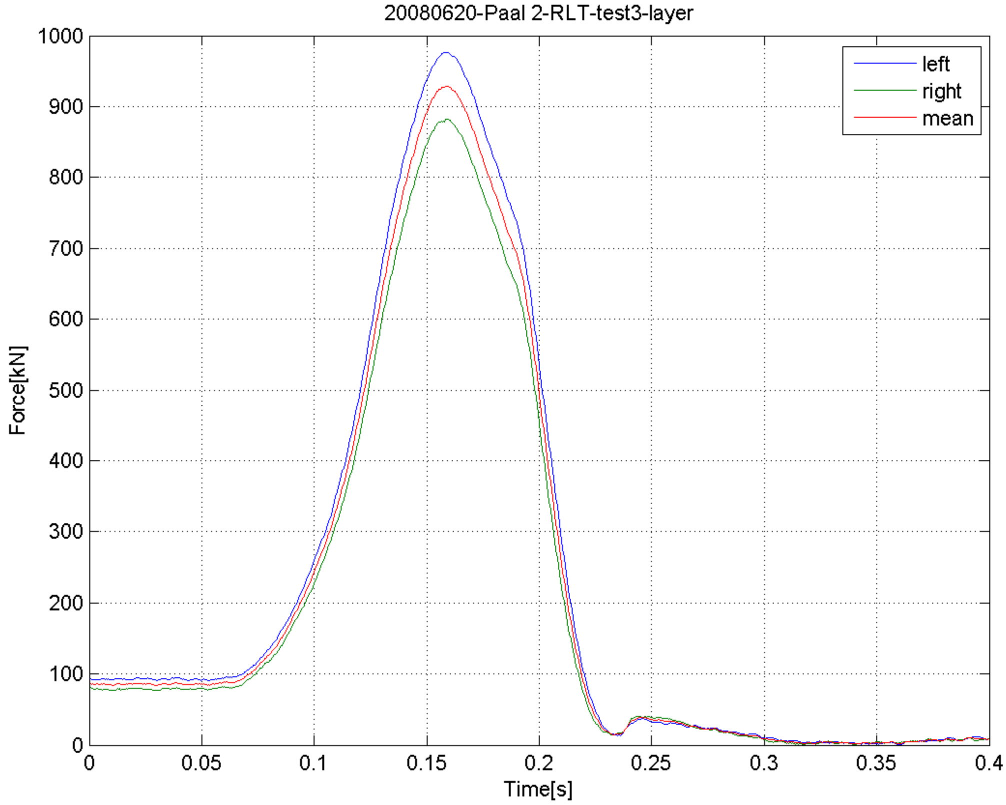

20080620-Paal 2-RLT-test2-head
Force[kN]
Time[s]
left
right
mean
1800
1600
1400
1200
1000
800
600
400
200
0
-200
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05

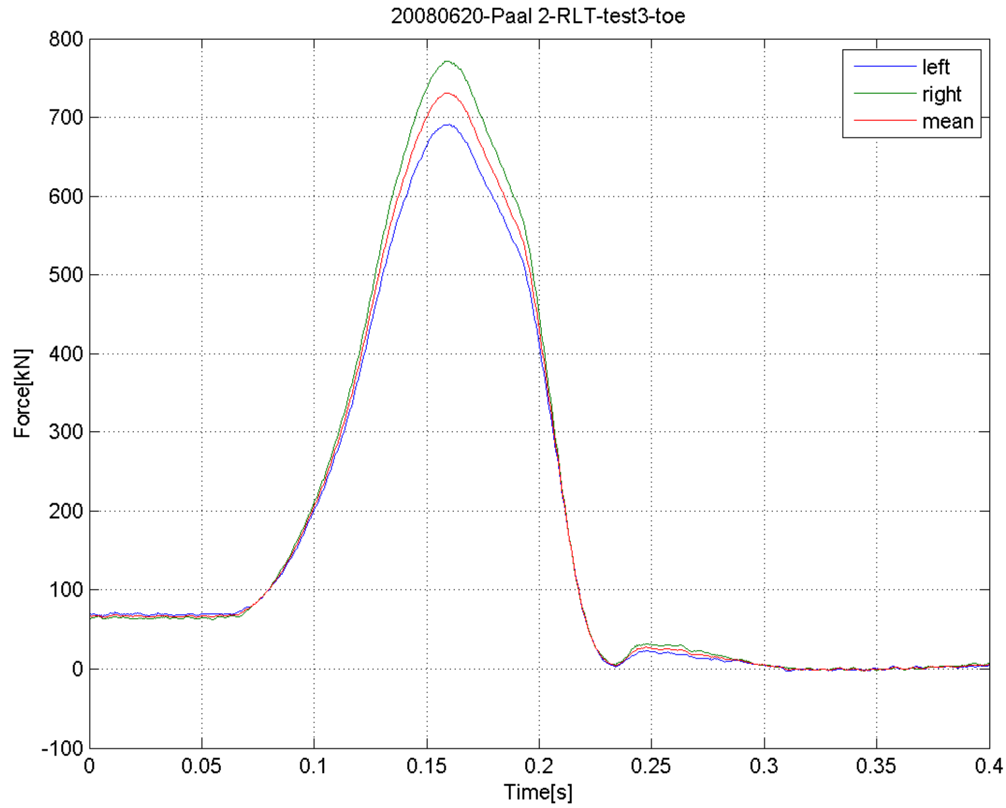

20080620-Paal 2-RLT-test2-layer
left
right
mean
Force[kN]
Time[s]
900
800
700
600
500
400
300
200
100
0
-100
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05

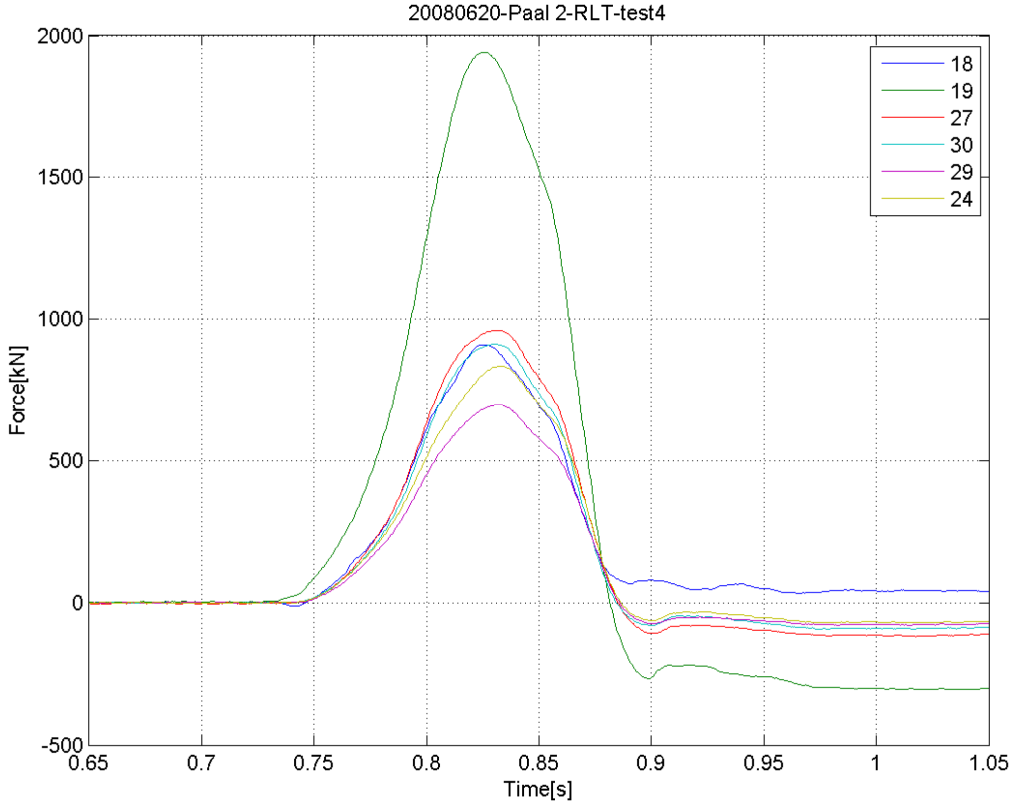

20080620-Paal 2-RLT-test2-toe
left
right
mean
Force[kN]
Time[s]
700
600
500
400
300
200
100
0
-100
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05

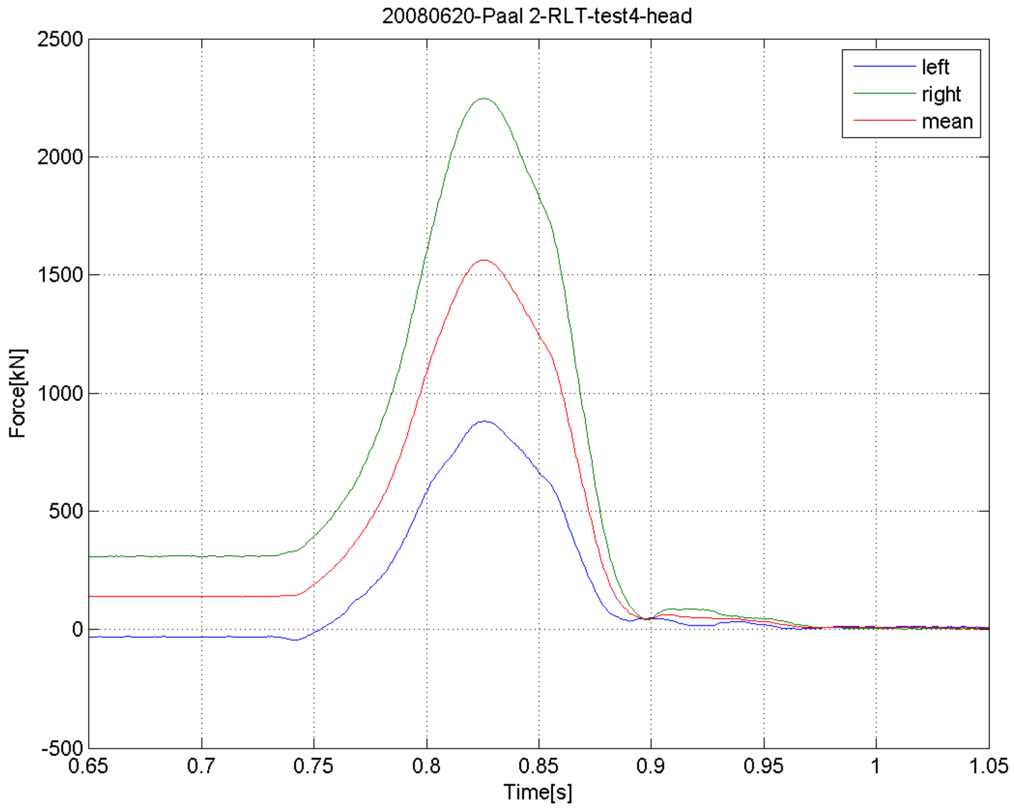

20080620-Paal 2-RLT-test3
Force[kN]
Time[s]
2000
1500
1000
500
0
-500
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
18
19
27
30
29
24

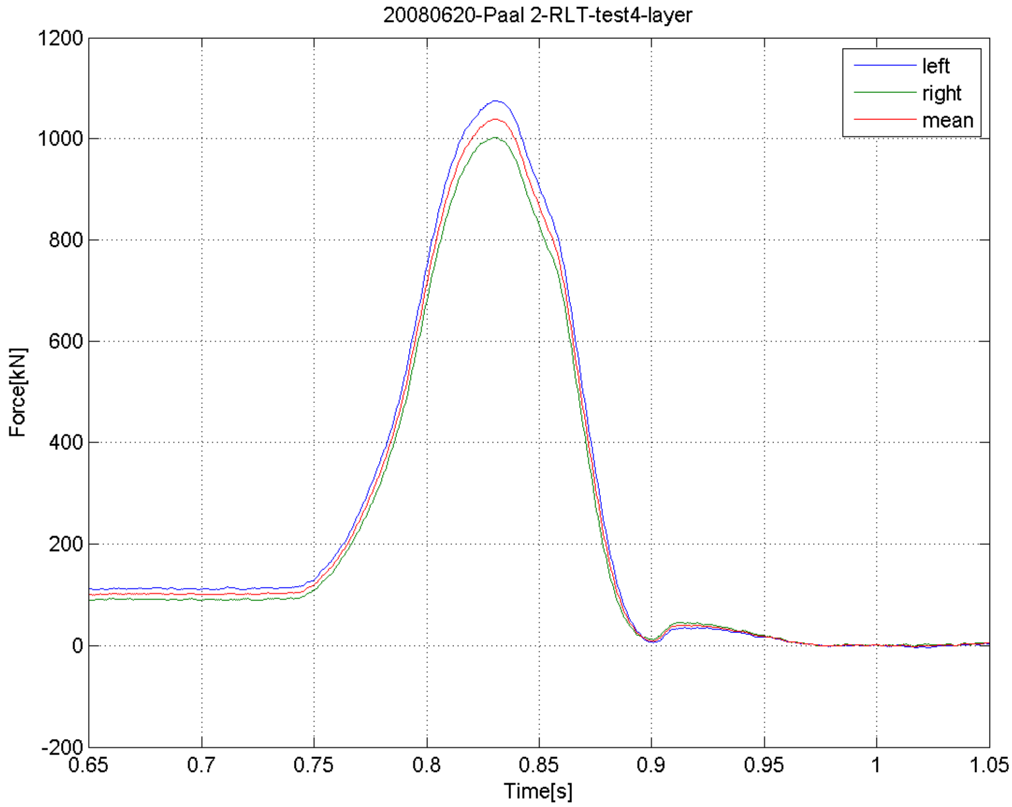

20080620-Paal 2-RLT-test3-head
Force[kN]
Time[s]
2000
1500
1000
500
0
-500
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
left
right
mean

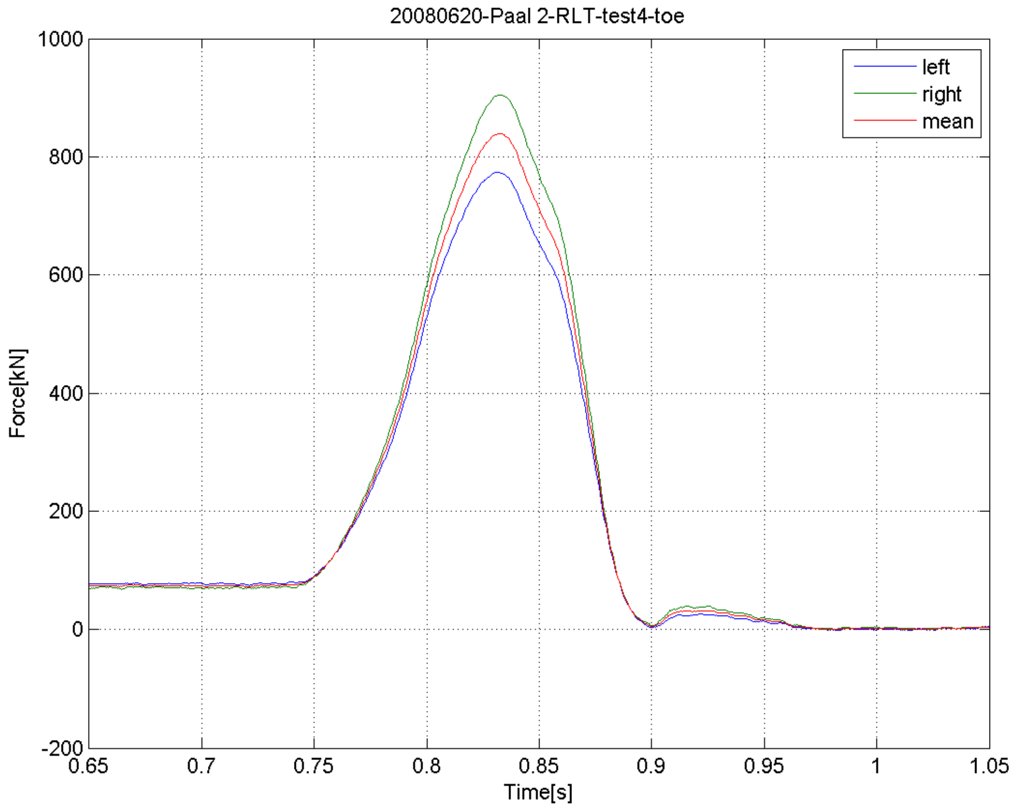

20080620-Paal 2-RLT-test3-layer
left
right
mean
Force[kN]
Time[s]
1000
900
800
700
600
500
400
300
200
100
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4


20080620-Paal 2-RLT-test3-toe
left
right
mean
Force[kN]
Time[s]
800
700
600
500
400
300
200
100
0
-100
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4


20080620-Paal 2-RLT-test4
Force[kN]
Time[s]
18
19
27
30
29
24
2000
1500
1000
500
0
-500
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05


20080620-Paal 2-RLT-test4-head
Force[kN]
Time[s]
left
right
mean
2500
2000
1500
1000
500
0
-500
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05


20080620-Paal 2-RLT-test4-layer
Force[kN]
Time[s]
left
right
mean
1200
1000
800
600
400
200
0
-200
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05


20080620-Paal 2-RLT-test4-toe
Force[kN]
Time[s]
left
right
mean
1000
800
600
400
200
0
-200
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05

G Results DLT

In this Appendix some results of the DLT are shown:

1. Quality of fit.
2. Quick overview of data.
3. Full input for interpretation.
4. Full out put for interpretation.

This is done for pile 1 (blow 2) and pile 2 (blow 2).

G.1 Pile 1, blow 2

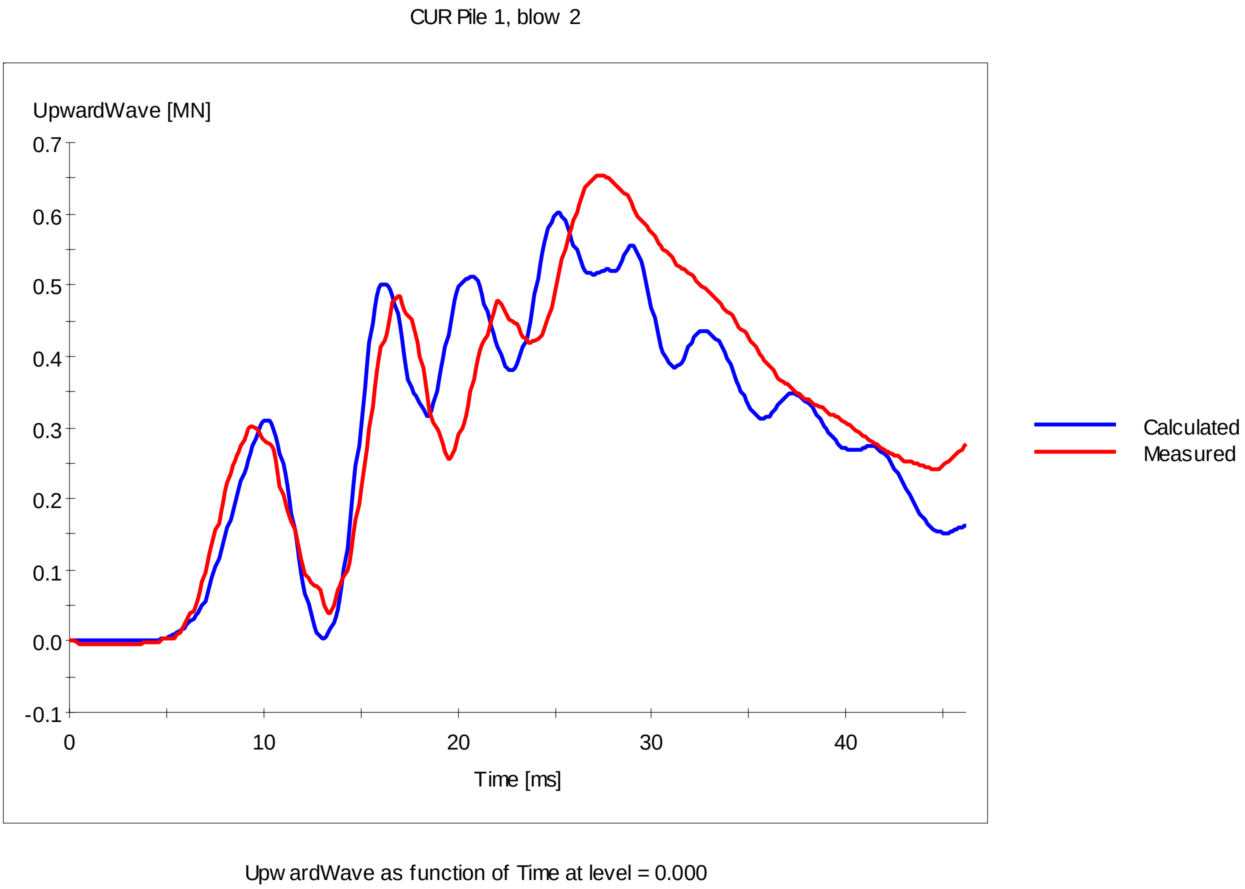


Figure G.1 Quality of fit DLT pile 1 blow 2

Transferred Energy	**16.8**	**[kNm]**	
at level	0	[m]	
Transferred Energy 2L/c	1.2	[kNm]	
at level	0	[m]	
Final set pile toe	6	[mm]	
Maximum pile toe displ.	9.1	[mm]	
Penetration pile toe	9.3	[m]	
Blow count	41.5	[bl/25cm]	
Set per 10 blows	60.3	[mm]	
Total driving resistance	1.421	[MN]	
Max. driving resistance	1.938	[MN]	
Mobilized static resistance	1.384	[MN]	
Mob. static resistance toe	1.016	[MN]	
Mob. static resistance shaft	0.368	[MN]	
Mob. static resistance toe	8.3	[MPa]	
Maximum stresses in pile			
Compression stress	20	[MPa]	
at level	1.8	[m]	
Tension stress	0	[MPa]	
at level	4.6	[m]	
Signal match quality			
Up to toe	0.2	[%]	(Excellent)
Toe 1	0.5	[%]	(Excellent)
Toe 2	0.6	[%]	(Excellent)
After Toe	0.6	[%]	(Excellent)
Overall	0.5	[%]	(Excellent)

Table G.1 Quick overview DLT pile 1, blow 2

CUR Pile 1, blow 2

Project ID	:82080118
Project Date	:27-10-2008
Project Time	:11:52:45
Program Version	:8.1.0
File Version	:"8.1.0"
Date Last Run	:27-10-2008
Time Last Run	:0:00:00

Input Data

Dimension Data

Part	Number	Type	Side 1	Side 2	Length
			[m]	[m]	[m]
Pile	1	Rectangular	0.35	0.35	9.8

Material Data

Part	Number	E-Modulus	Density
		[MPa]	[kg/m3]
Pile	1	43000	2400

Soil investigation data

Layer No.	Level	Depth	Thick ness	Cone Resist.	Shaft Friction	Friction Ratio	Soil Type
		[m]	[m]	[MPa]	[KPa]	[%]	[-]
1	Top	-5.1	1.3	2	7.5	0.5	Sand
	Bottom		-6.4	2	7.5	0.5	
2	Top	-6.4	3.3	1	10	2	Clay
	Bottom		-9.7	1	10	2	
3	Top	-9.7	2.3	1	5	1	Peat
	Bottom		-12	1	5	1	
4	Top	-12	2.25	9	45	0.5	Sand
	Bottom		-14.25	9	45	0.5	
5	Top	-14.25	2.25	0	0	0	None
	Bottom		-16.5	0	0	0	
6	Top	-16.5	2.25	0	0	0	None
	Bottom		-18.75	0	0	0	
7	Top	-18.75	2.25	0	0	0	None
	Bottom		-21	0	0	0	

Shaft soil model input
Soil Model = TNO Model

Layer No.	Level	Depth	Yield stress	Uq1	Uq2	Yield factor	Beta	C1	C2	Alfa
		[m]	[KPa]	[mm]	[mm]	-	-	[MNs/m3]	[MNs/m3]	-
1	Top	-5.1	47.6	2.4	2.3	1.062	1	0.001	0.001	1.428
	Bottom	-6.4	46.7	2.6	2.4	1.019	1	0.001	0.001	1.069
2	Top	-6.4	17.4	1.4	0.2	0.508	1	0.137	0.005	0.657
	Bottom	-9.7	18.2	1.5	-9.4	0.597	1	0.127	0.005	0.217
3	Top	-9.7	3.8	1.9	1.9	0.795	1	0.002	0.002	0.181
	Bottom	-12	4.4	1.9	1.9	0.738	1	0.002	0.002	0.371
4	Top	-12	60.2	1.6	0.2	0.534	1	0.004	0.005	1.283
	Bottom	-14.25	50.9	1.6	0.2	0.57	1	0.004	0.005	1.14
5	Top	-14.25	56	1.6	0.3	0.707	1	0.004	0.005	1.202
	Bottom	-16.5	45.9	1.7	0.4	0.679	1	0.004	0.005	1.138
6	Top	-16.5	65.5	1.7	0.4	0.679	1	0.004	0.005	1.138
	Bottom	-18.75	32.5	1.8	0.5	0.638	1	0.004	0.005	1.084
7	Top	-18.75	32.5	1.8	0.5	0.638	1	0.004	0.005	1.084
	Bottom	-21	19.4	1.9	0.6	0.598	1	0.005	0.005	1.031

Toe soil model input
Soil Model = TNO Model

Layer No.	Level stress	Depth factor	Yield	Uq1	Uq2	Yield	Beta	C1	C2	Alfa
		[m]	[MPa]	[mm]	[mm]	-	-	[MNs/m3]	[MNs/m3]	-
	Top	-14.25	8	6.3	5.4	0.415	1	0.867	0.395	1.8
	Bottom	-16.5	8	6.3	5.4	0.415	1	0.867	0.395	1.8

Output Data

Total mobilised static resistance	1.384	[MN]
Static mobilised shaft resistance	0.368	[MN]
Static mobilised toe resistance	1.016	[MN]

Modelled and mobilised static resistance

Layer	Depth	Modelled Res.	Mobilised Res.	
	[m]	[MN]	[MN]	
1	-5.1	0.086	0.086	
2	-6.4	0.082	0.082	
3	-9.7	0.013	0.013	
4	-12	0.175	0.175	
5	-14.25	0.012	0.012	
6	-16.5	0	0	
7	-18.75	0	0	
		---------	---------	
Shaft		0.368	0.368	[MN]
Toe		1.016	1.016	[MN]
		---------	---------	
Total		1.384	1.384	[MN]

Mobilised static resistance

Layer	Depth	Mobilised Res.	
	[m]	[MN]	
1	-5.1	0.086	
2	-6.4	0.082	
3	-9.7	0.013	
4	-12	0.175	
5	-14.25	0.012	
6	-16.5	0	
7	-18.75	0	

Shaft		0.368	[MN]
Toe		1.016	[MN]

Total		1.384	[MN]

G.2 Pile 2 Blow 2

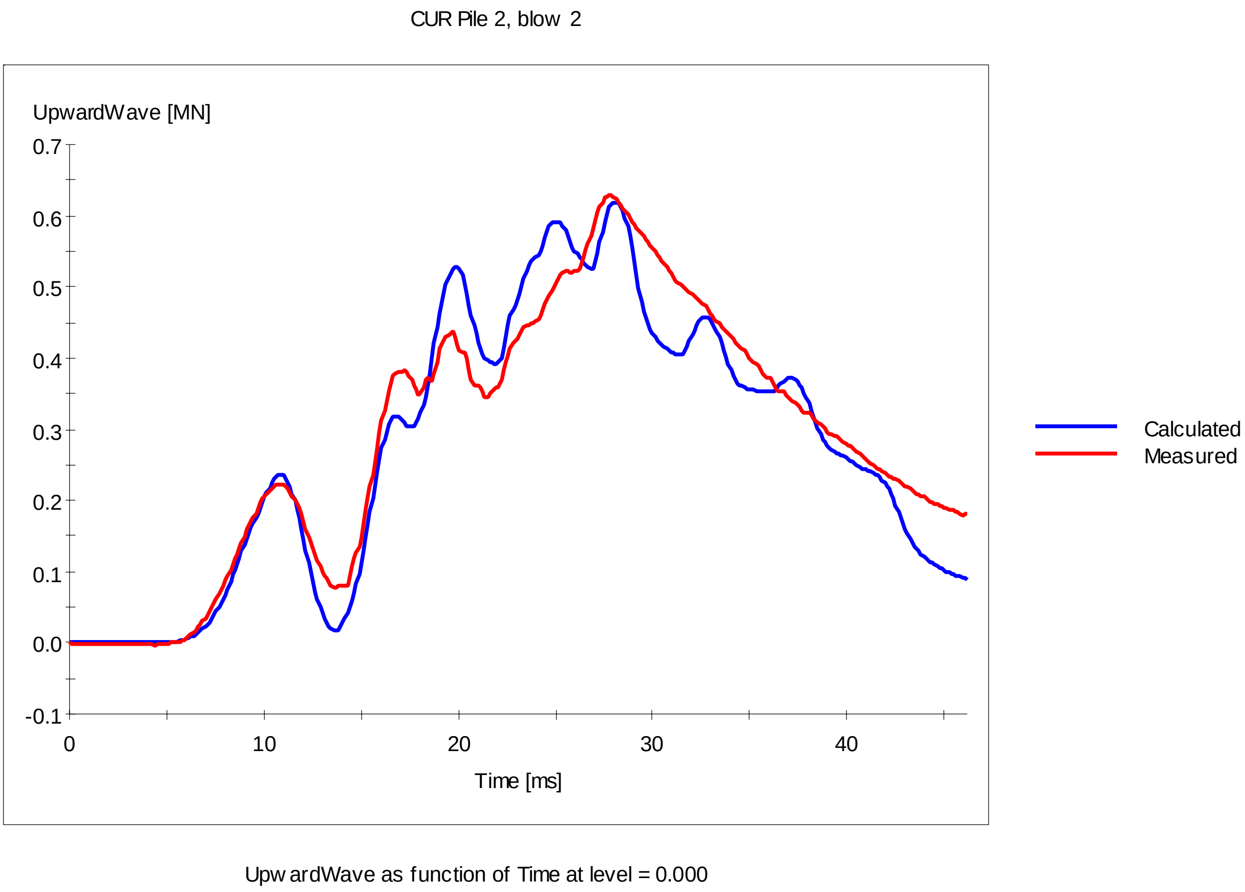


Figure G.2 Quality of fit pile 2 blow 2

Transferred Energy		**20.2**	**[kNm]**	
	at level	0	[m]	
Transferred Energy 2L/c		1	[kNm]	
	at level	0	[m]	
Final set pile toe		7.1	[mm]	
Maximum pile toe displ.		11.1	[mm]	
Penetration pile toe		9.3	[m]	
Blow count		35.1	[bl/25cm]	
Set per 10 blows		71.3	[mm]	
Total driving resistance		1.346	[MN]	
Max. driving resistance		2.073	[MN]	
Mobilized static resistance		1.465	[MN]	
Mob. static resistance toe		1.158	[MN]	
Mob. static resistance shaft		0.307	[MN]	
Mob. static resistance toe		9.5	[MPa]	
Maximum stresses in pile				
Compression stress		21	[MPa]	
	at level	0.5	[m]	
Tension stress		0	[MPa]	
	at level	5.1	[m]	
Signal match quality				
	Up to toe	0.1	[%]	(Excellent)
	Toe 1	0.5	[%]	(Excellent)
	Toe 2	0.6	[%]	(Excellent)
	After Toe	0.6	[%]	(Excellent)
	Overall	0.5	[%]	(Excellent)

Table G.2 Quick overview of data DLT 2 blow 2

CUR Pile 2, blow 2

Project ID	:82080118
Project Date	:27-10-2008
Project Time	:13:02:28
Program Version	:8.1.0
File Version	:"8.1.0"
Date Last Run	:27-10-2008
Time Last Run	:0:00:00

Input Data

Dimension Data

Part	Number	Type	Side 1 [m]	Side 2 [m]	Length [m]
Pile	1	Rectangular	0.35	0.35	9.8

Material Data

Part	Number	E-Modulus [MPa]	Density [kg/m3]
Pile	1	43000	2400

Soil investigation data

Layer No.	Level	Depth [m]	Thick ness [m]	Cone Resist. [MPa]	Shaft Friction [KPa]	Friction Ratio [%]	Soil Type [-]
1	Top	-5.1	1.3	2	7.5	0.5	Sand
	Bottom	-6.4		2	7.5	0.5	
2	Top	-6.4	3.3	1	10	2	Clay
	Bottom	-9.7		1	10	2	
3	Top	-9.7	2.3	1	5	1	Peat
	Bottom	-12		1	5	1	
4	Top	-12	2.25	9	45	0.5	Sand
	Bottom	-14.25		9	45	0.5	
5	Top	-14.25	2.25	0	0	0	None
	Bottom	-16.5		0	0	0	
6	Top	-16.5	2.25	0	0	0	None
	Bottom	-18.75		0	0	0	
7	Top	-18.75	2.25	0	0	0	None
	Bottom	-21		0	0	0	

Shaft soil model input
Soil Model = TNO Model

Layer No.	Level	Depth [m]	Yield stress [KPa]	Uq1 [mm]	Uq2 [mm]	Yield factor -	Beta -	C1 [MNs/m3]	C2 [MNs/m3]	Alfa -
	Top	-5.1	21.4	2.1	2.1	1.048	1	0.001	0.001	1.397
	Bottom	-6.4	23.8	2.2	2.2	1.003	1	0.001	0.001	1.054
	Top	-6.4	16.8	1.4	0.2	0.507	1	0.106	0.005	0.598
	Bottom	-9.7	17.6	1.5	0.6	0.596	1	0.102	0.005	0.184
	Top	-9.7	3.8	1.9	1.9	0.795	1	0.002	0.002	0.181
	Bottom	-12	4.3	1.9	1.9	0.738	1	0.002	0.002	0.372
	Top	-12	55.6	1.6	0.2	0.536	1	0.004	0.005	1.273
	Bottom	-14.25	47.5	1.6	0.2	0.572	1	0.004	0.005	1.132
	Top	-14.25	55.7	1.6	0.3	0.708	1	0.004	0.005	1.201
	Bottom	-16.5	45.9	1.7	0.4	0.679	1	0.004	0.005	1.138
	Top	-16.5	65.5	1.7	0.4	0.679	1	0.004	0.005	1.138
	Bottom	-18.75	32.5	1.8	0.5	0.638	1	0.004	0.005	1.084
	Top	-18.75	32.5	1.8	0.5	0.638	1	0.004	0.005	1.084
	Bottom	-21	19.4	1.9	0.6	0.598	1	0.005	0.005	1.031

Toe soil model input
Soil Model = TNO Model

Layer No.	Level stress	Depth factor [m]	Yield [MPa]	Uq1 [mm]	Uq2 [mm]	Yield -	Beta -	C1 [MNs/m3]	C2 [MNs/m3]	Alfa -
	Top	-14.25	9	6.4	5.4	0.303	1	0.972	0.395	1.655
	Bottom	-16.5	9	6.4	5.4	0.303	1	0.972	0.395	1.655

Output Data

Total mobilised static resistance	1.465	[MN]
Static mobilised shaft resistance	0.307	[MN]
Static mobilised toe resistance	1.158	[MN]

Modelled and mobilised static resistance

Layer	Depth	Modelled Res.	Mobilised Res.	
	[m]	[MN]	[MN]	
1	-5.1	0.041	0.041	
2	-6.4	0.079	0.079	
3	-9.7	0.013	0.013	
4	-12	0.162	0.162	
5	-14.25	0.012	0.012	
6	-16.5	0	0	
7	-18.75	0	0	
		---------	---------	
Shaft		0.307	0.307	[MN]
Toe		1.158	1.158	[MN]
		---------	---------	
Total		1.465	1.465	[MN]

Mobilised static resistance

Layer	Depth	Mobilised Res.	
	[m]	[MN]	
1	-5.1	0.041	
2	-6.4	0.079	
3	-9.7	0.013	
4	-12	0.162	
5	-14.25	0.012	
6	-16.5	0	
7	-18.75	0	

Shaft		0.307	[MN]
Toe		1.158	[MN]

Total		1.465	[MN]

H Some results for corrected strain gauge 19 pile 1

This Appendix shows some results with the results for strain gauge 19 in Pile 1 (here called right) corrected based on the results described in Section 8.2. The measured values are divided by 1.6. The results for the Stages 4, 5 and 6 are shown. The Figures are comparable with the figures for the pile head in Appendix F.1.

H.1 Pile 1 Stage 4

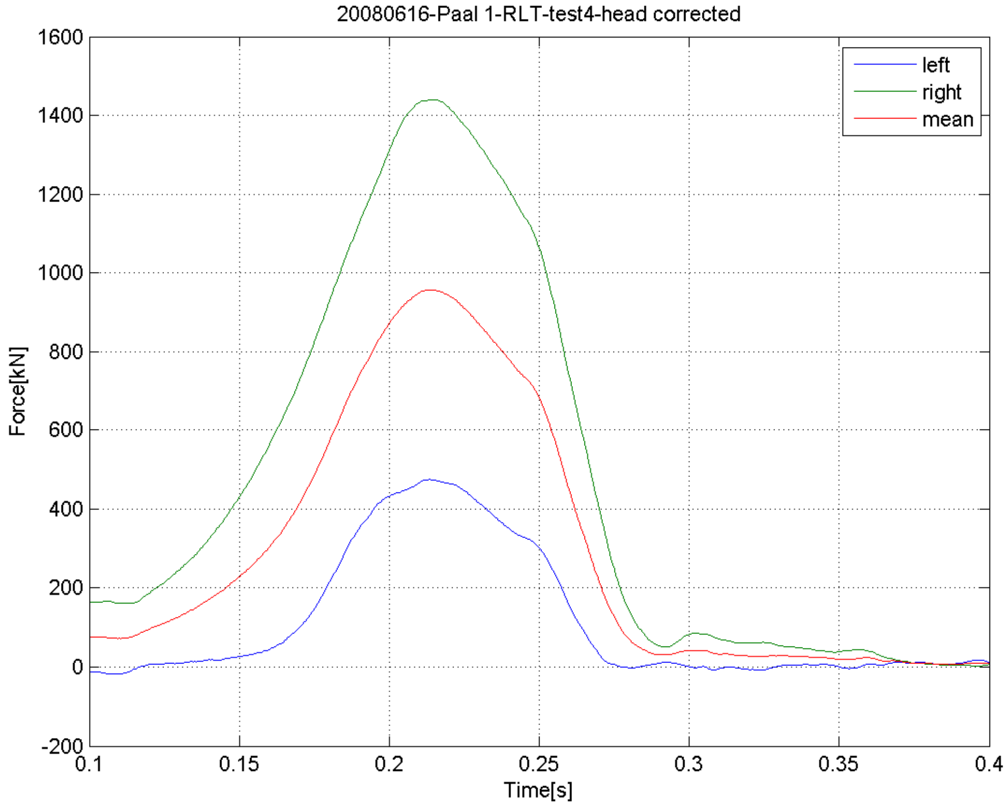


Figure H.1 Result from strain gauges 18 and 19 in head of Pile 1 after correction, stage 4

H.2 Pile 1 Stage 5

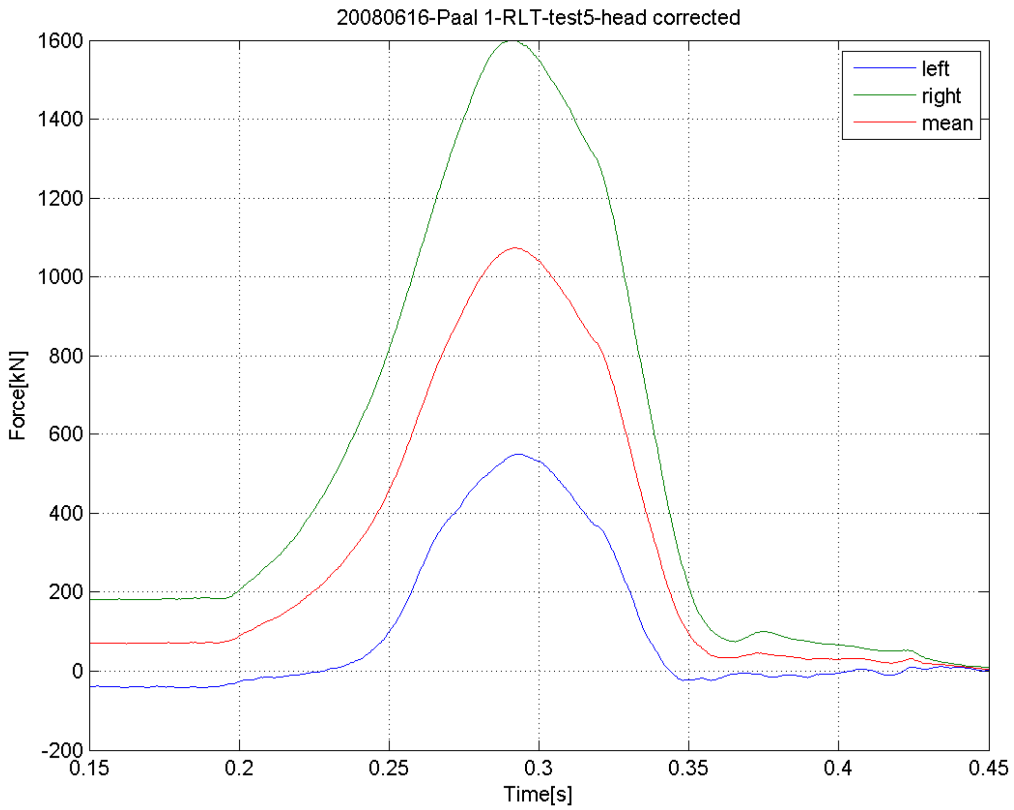


Figure H.2 *Result from strain gauges 18 and 19 in head of Pile 1 after correction, stage 5*

H.3 Pile 1 Stage 6

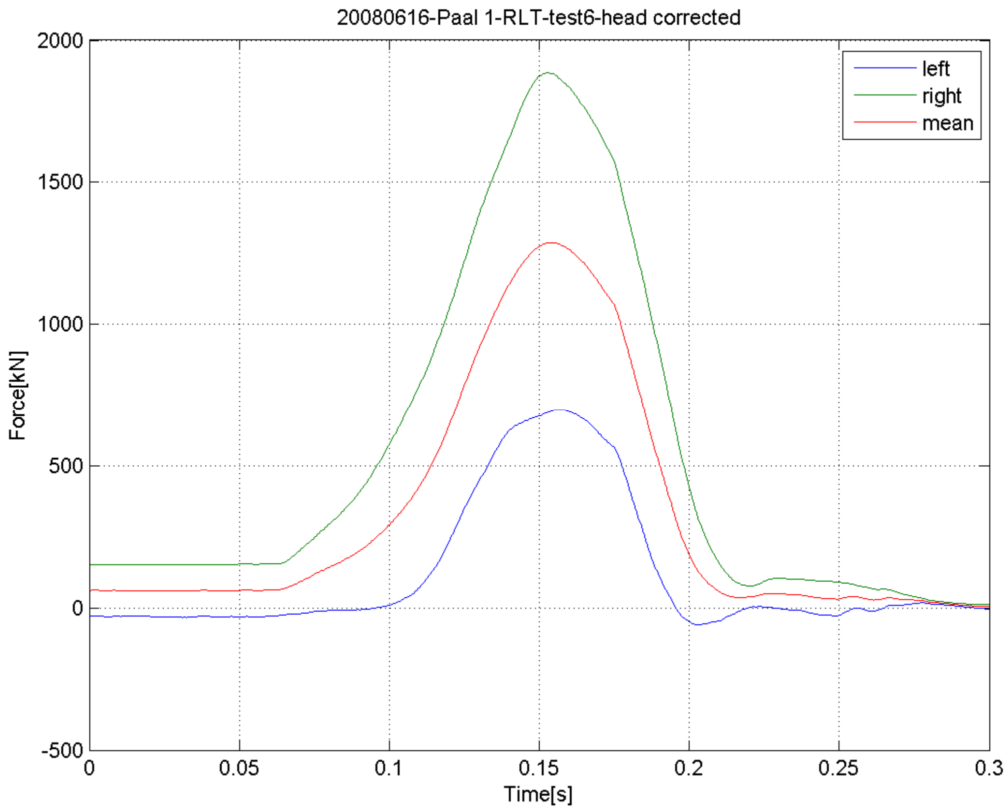


Figure H.3 *Result from strain gauges 18 and 19 in head of Pile 1 after correction, stage 6*