Experimental Investigation Composite sheet piles

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Project name: Opwaardering Twentekanalen
Client: Rijkswaterstaat GPO
Contractor: Combinatie Van Oord, Hakkers, Beens
Sub contractor: Witteveen+Bos, TU/e, Dept. of Built Environment

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Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

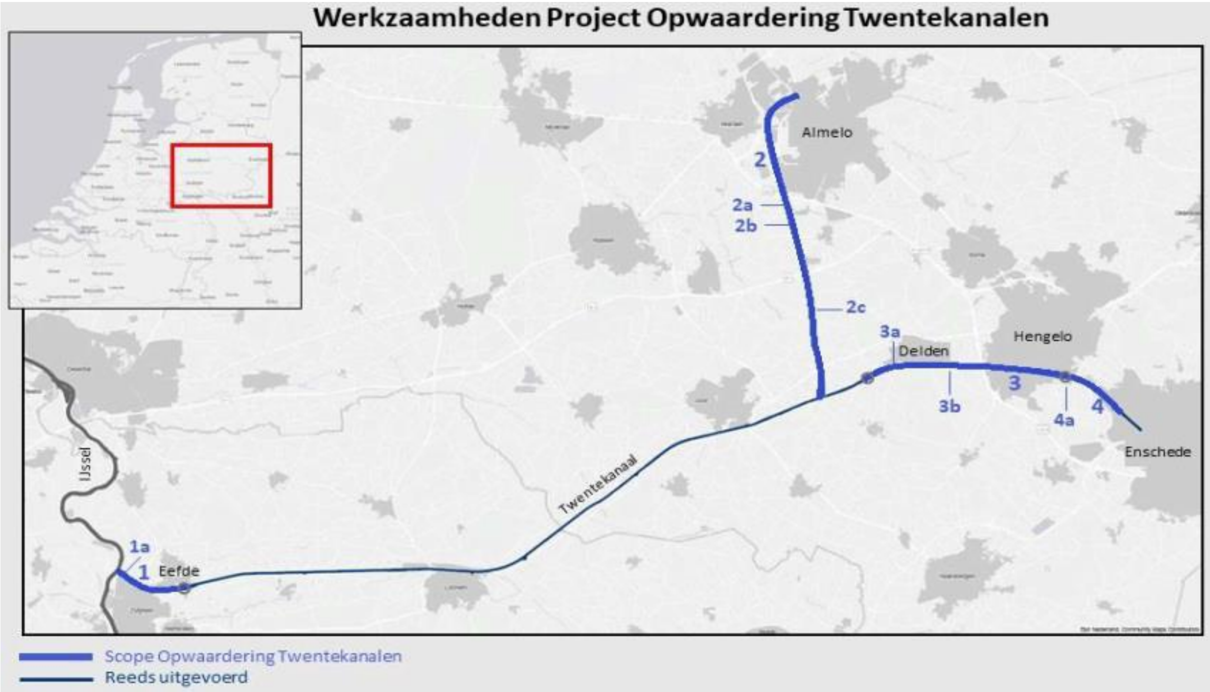


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometre points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance. The following tests have been conducted:

1. Report Longitudinal tensile tests;
2. Report Transverse tensile tests;
3. Report Longitudinal compressive tests;
4. Report Transverse compressive tests;
5. Report 3-point bending punching shear;
6. Report Tensile lock test;
7. Report Bearing response bolted connections;
8. Report full scale tests lab;
9. Report full scale tests outside.

This report will wrap up all the results obtained from all the tests conducted on the composite sheet piles. The reports are added to the appendix.

2 Sheet piles tested

This report summarizes the results obtained from the composite sheet pile tests. The results are compared with the design parameters given by the producer.

The sheet piles are constructed from pultruded glass fibre polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in³/ft	703.22	cm³/m
Moment of Inertia	54.01	in⁴/ft	7375.52	cm⁴/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in²	47.94	cm²
Standard Color	Graphite Gray			

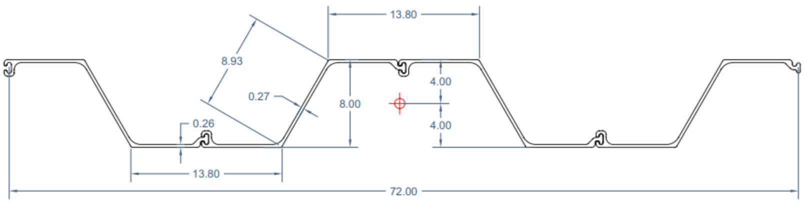
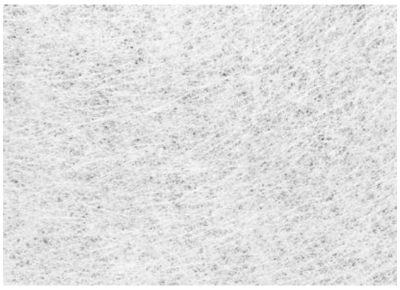


Figure 2-1 Superloc Series 1580

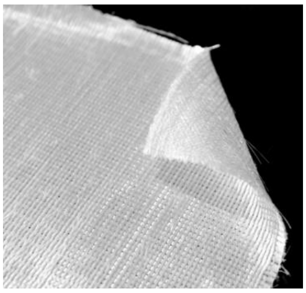
The glass fibre volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibres on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament



0/90 Fabric

0 Direction

Figure 2-2 Visual representation glass fibres used

Figure 2-3 gives the physical and mechanical properties of the 1580 PE composite sheet pile according to the producer.

SuperLoc® Sheet Piles - Series 1580 (SS860)

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Mechanical Properties	Test Method	ASTM D7290-06 Characteristic Values – Polyester Resin – Metric	Units
Tensile Modulus (LW)	ASTM D638	22.96	GPa
Tensile Modulus (CW)	ASTM D638	8.41	GPa
Compression Modulus (LW)	ASTM D6641	24.82	GPa
Compression Modulus (CW)	ASTM D6641	6.07	GPa
Tensile Strength (LW)	ASTM D638	459.76	MPa
Tensile Strength (CW)	ASTM D638	43.53	MPa
Compression Strength (LW)	ASTM D6641	335.68	MPa
Compression Strength (CW)	ASTM D6641	95.66	MPa
Inplane Shear Strength	ASTM D5379	31.1	MPa
Inplane Shear Modulus	ASTM D5379	3.45	GPa
Short Beam Shear Strength	ASTM D2344	26.1	MPa

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Mechanical Properties	
Moment Capacity	**Metric**
Moment Capacity Polyester[1]	66.3 kN-m/meter of wall
Shear Strength	**Metric**
Shear Strength Vinyl Ester[1]	455.4 kN/meter of wall
Full Section Modulus of Elasticity	**Metric**
Average Full Section Modulus of Elasticity[2]	30.41 GPa (Polyester) 31.44 GPa (Vinyl Ester)
Web Buckling Capacity from Wale Force (based on 8" wale section)	91.20 kN/m

Design Notes & Considerations:

[1]Ultimate Capacity based on ASTM D 7290-06 Characteristic Values

[2]Utilize Average Full Section Modulus for Deflection Calculations

Figure 2-3 Physical and mechanical properties

The creative composite group did pin bearing tests on pultruded composite material. Based on the outcome of those tests it's possible to determine the bearing capacity per bolt diameter.

SuperLoc Sheet Piles -Series 1580 (SS860)					
	Diameter	AV. Bearing capacity (LW)	Char. Bearing capacity (LW)	AV. Bearing capacity (CW)	Char. Bearing capacity (CW)
Bout	[mm]	[kN]	[kN]	[kN]	[kN]
M10	10	13	10	6	4
M12	12	15	12	7	5
M14	14	18	13	8	5
M16	16	20	15	9	6
M20	20	25	19	12	8
M24	24	30	23	14	9
M27	27	34	26	16	10
M30	30	38	29	18	12
M36	36	45	35	21	14
M42	42	53	40	25	16

Minimal dimentions washer			
	Diameter bout d_b	Min. diameter washer d_r	thickness washer t_r
Bout	[mm]	[mm]	[mm]
M10	10	22	2.2
M12	12	26	2.6
M14	14	31	3.1
M16	16	35	3.5
M20	20	44	4.4
M24	24	53	5.3
M27	27	59	5.9
M30	30	66	6.6
M36	36	79	7.9
M42	42	92	9.2

Table 2-1: Bolt bearing capacity

3 Results

3.1 Longitudinal tensile tests

The results obtained from the longitudinal tensile tests are summarized in Table 3-1.

Results tensile strength longitudinal direction	
Characteristic Strength	37.09 kN
Characteristic Stress	552.3 MPa
Characteristic Maximal Strain	1.76%
Characteristic E-Modulus	30079 MPa

table 3-1 Material properties according to tensile test

3.2 Transverse tensile tests

The results obtained from the transverse tensile tests are summarized in Table 3-2.

Results tension in transverse direction	
Characteristic Strength	8.4 kN
Characteristic Stress	51.54 MPa
Characteristic Strain at failure	2.19 %
Characteristic E-Modulus	4053 MPa

table 3-2 Material properties according to tensile test

3.3 Longitudinal compressive tests

The results obtained from the longitudinal compressive tests are summarized in Table 3-3.

Results compression in longitudinal direction	
Characteristic Strength	34.0 kN
Characteristic Stress	508.4 MPa
Characteristic Maximal Strain	1.87%*
Characteristic E-Modulus	25888 MPa*

table 3-3 Material properties according to compressive test

** Characteristic Maximal Strain and E-Modulus are retrieved from the strain/kN from the manufacturer. This is calculated by*

3.4 Transverse compressive tests

The results obtained from the transverse compressive tests are summarized in Table 3-4.

Results compression strength transverse direction	
Characteristic Strength	10.1 kN
Characteristic Stress	60.8 MPa
Characteristic Maximal Strain	1.75%*
Characteristic E-Modulus	8605 MPa*

table 3-4 Material properties according to compressive test

** Characteristic Maximal Strain and E-Modulus are retrieved from the strain/kN from the manufacturer. This is calculated by*

3.5 3-point bending punching shear

The results obtained from the 3-point bending punching shear tests are summarized in Table 3-5.

Results punching strength	
Characteristic 1st punching failure strength M24 - 44 mm washer	12.4 kN
Characteristic 1st punching failure stress M24- 44 mm washer	361 MPa
Characteristic punching failure strength M24- 44 mm washer	15.7 kN
Characteristic punching failure stress M24- 44 mm washer	453 MPa
Theoretical maximum punching failure strength M24 - 44 mm washer	12.1 kN
Characteristic 1st punching failure strength M30- 44 mm washer	12.8 kN
Characteristic 1st punching failure stress M30- 44 mm washer	407 MPa
Characteristic punching failure strength M30- 44 mm washer	15.4 kN
Characteristic punching failure stress M30- 44 mm washer	491 MPa
Theoretical maximum punching failure strength M30 - 44 mm washer	12.1 kN

Table 3-5: Characteristic punching shear properties, retrieved from the tests

3.6 Tensile lock test

The results obtained from the tensile lock tests are summarized in Table 3-6.

Results lock	
Characteristic 1st tensile lock strength	0.40 kN
Characteristic tensile lock strength	0.57 kN

Table 3-6: Characteristic tensile lock properties, retrieved from the tests

3.7 Bearing response bolted connections

The results obtained from the bolted connection tests are summarized in Table 3-7.

Bearing response test M30 bolted connection in shear	
Characteristic first-ply failure	28.9 kN
Characteristic Force at failure	37.9 kN
Characteristic maximum bearing strength	188.6 MPa
Characteristic initial peak bearing strength	180 MPa
Characteristic bearing strain at failure	7.1%
Characteristic initial peak bearing strain	7.0%
Characteristic bearing chord stiffness	2373 MPa

Table 3-7: Characteristic bearing properties, retrieved from the tests

3.8 Full scale tests lab

The ultimate failure loads and failure type of the full scale lab tests is presented in Table 3-8. The Web buckling capacity - 203.2 mm waler front side - backside fully supported - 90 degree anchor is determined by the Creative composite group themselves. If we compare the results where local buckling occurred than it can be concluded that they are all in the same range.

Test	Max. Failure load (kN)	Max. Failure load (kN/m)(2)	Fzt,1,Rk (kN)	Fzt,1,Rk (kN/m)(2)	Failure type
Web buckling capacity - 203.2 mm (8'') waler front side - backside fully supported - 90 degree anchor	94.3	103.1	83.4	91.2	local buckling
Anchor plate type 1 (300x300) with softwood filler plates in between sheet pile and wale beam (100 mm)	40	43.7	30.7(1)	33.6(1)	Punching shear
Anchor plate type 2 (300x300 + fill plate overlapping the belly of the sheet pile) with softwood filler plates in between sheet pile and wale beam (100 mm)	61.7 / 96.6	67.5 / 102.4	47.4(1) / 70.6(1)	51.8(1) / 77.2(1)	local buckling
Anchor plate type 2 (300x300 + fill plate overlapping the belly of the sheet pile) with steel filler plates in between sheet pile and wale beam (100 mm)	93.6	102.4	71.81)	78.51)	local buckling

(1) Estimated with a coefficient of variation of 10%
(2) sheet pile width is 0.9144 m

table 3-8 Failure loads according to full scale lab. tests

3.9 Full scale tests outside

The results obtained from the full scale tests outside are summarized in Table 3-9.

Test	Max. Failure load (kN)	Failure type
1 location 3	44.5	punching shear and delamination
2 location 2	84.1	local buckling and delamination
3 location 1	125.6	local buckling, bearing capacity and delamination

table 3-9 Failure loads according to full scale outdoor tests

4 Comparison

All the results are comparted with the design data of the producer.

Series 1580 (Polyester Resin)	ASTM Characteristic values Producer	Characteristic values TU/e		%	Remarks
Tensile strength (LW)	459.76	552.3	MPa	16.8	
Tensile modulus (LW)	22.96	30.08	GPa	23.7	
Tensile strength (CW)	43.53	51.54	MPa	15.5	
Tensile modulus (CW)	8.41	4.05	GPa	-108	Much lower results, in our tests 1 of the 0/90 ply's fails instead of two togheter
Compression Strength (LW)	335.68	508.4	MPa	34	Much higher results, different testmethod (ASTM D3410 in stead of ASTM D6641) and wider specimen (x2)
Compression Modulus (LW)	24.82	25.9	GPa	4.17	
Compression Strength (CW)	95.66	60.8	MPa	-57.3	Much lower results, different testmethod (ASTM D3410 in stead of ASTM D6641) and wider specimen (x2)
Compression Modulus (CW)	6.07	8.6	GPa	29.4	
Inplane Shear Strength	31.1	-	MPa		
Inplane Shear Modulus	3.45	-	GPa		
Short Beam Shear Strength	26.1	-	MPa		
Moment Capacity	26.3	-	kNm/meter of wall		
Shear Strength	384.1	-	kN/meter of wall		
Average Full Section Modulus of Elasticity	30.41	34.62	GPa	12.2	
Web buckling capacity - 203.2 mm (8”) waler front side - backside fully sup-ported - 90 degree anchor	91.2	-	kN/meter of wall		
Anchor plate type 1 (300x300) with softwood filler plates in between sheet pile and wale beam (100mm)	-	33.6	kN/meter of wall		
Anchor plate type 2 (300x300 + fill plate over-lapping the belly of the sheet pile) with soft-wood filler plates in between sheet pile and wale beam (100mm)	-	51.8(*) /77.2	kN/meter of wall		(*) = first failure
Anchor plate type 2 (300x300 + fill plate over-lapping the belly of the sheet pile) with steel filler plates in between sheet pile and wale beam (100mm)	-	78.5	kN/meter of wall		
Bearing strength M10 (LW)	10		kN		
Bearing strength M12 (LW)	12		kN		
Bearing strength M14 (LW)	13		kN		
Bearing strength M16 (LW)	15		kN		
Bearing strength M20 (LW)	19		kN		
Bearing strength M24 (LW)	23		kN		
Bearing strength M27 (LW)	26		kN		
Bearing strength M30 (LW)	29	29.0	kN	0	
Bearing strength M36 (LW)	35		kN		
Bearing strength M42 (LW)	40		kN		
Bearing strength M10 (CW)	4		kN		
Bearing strength M12 (CW)	5		kN		
Bearing strength M14 (CW)	5		kN		
Bearing strength M16 (CW)	6		kN		
Bearing strength M20 (CW)	8		kN		
Bearing strength M24 (CW)	9		kN		
Bearing strength M27 (CW)	10		kN		
Bearing strength M30 (CW)	12		kN		
Bearing strength M36 (CW)	14		kN		
Bearing strength M42 (CW)	16		kN		
Punching capacity bolt M24 with washer 44mm	-	12.4	kN		
Punching capacity bolt M30 with washer 44mm	-	12.8	kN		

Table 4-1: Comparison

5 Appendix

5.1 Appendix A – Report Longitudinal tensile tests

Longitudinal tensile tests composite sheet piles

ASTM D3039 - 17
NEN-EN-ISO 527-4

Project name: Opwaardering Twentekanalen
Client: Rijkswaterstaat GPO
Contractor: Combinatie Van Oord, Hakkers, Beens
Sub contractor: Witteveen+Bos, TU/e, Dept. of Built Environment

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	Checked by			
	Lab Technician(s)			

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Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date tested:	08-03-2023
Test standards:	ASTM D3039 - 17 / NEN-EN-ISO 527-4
Material:	E-glass, polyester
Specimen type:	ISO 527-5 A (parallel)
Pre-treatment:	21 °C / 45-50% RV
Machine:	Instron 5985
Pre-load:	0 MPa
Test speed:	2 mm/min
Gage length, standard travel:	50 mm

Table of content

1 Introduction

1.1 Project description

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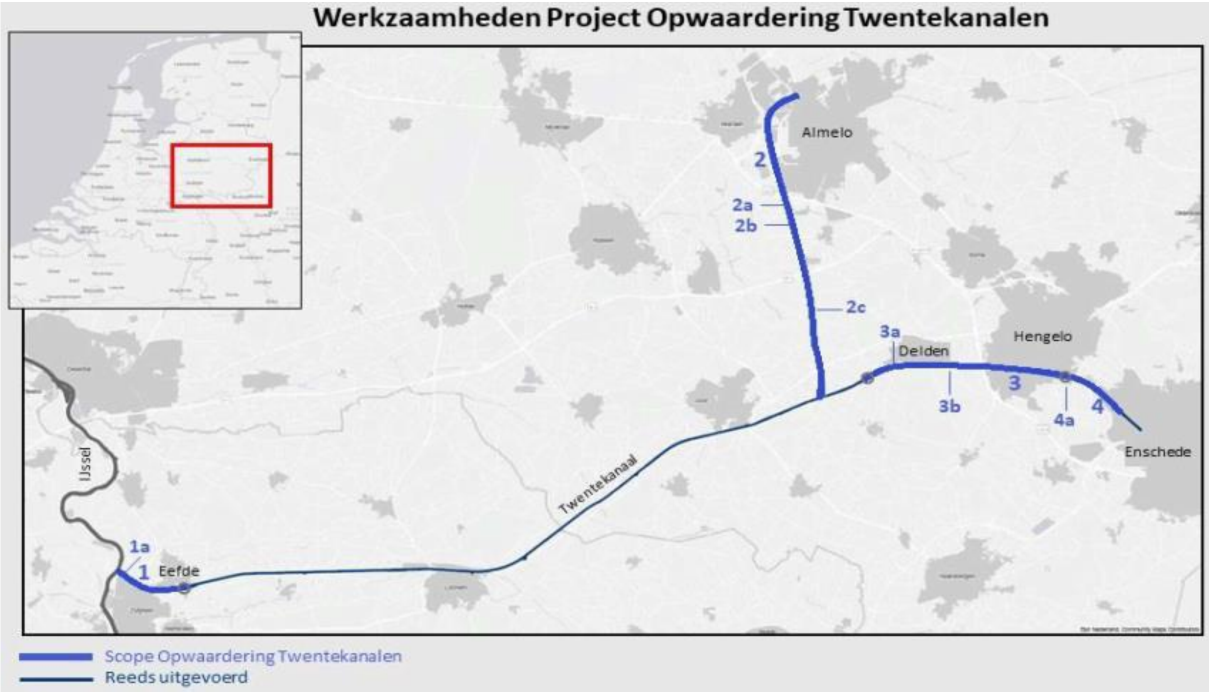

Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometre points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **tensile tests in longitudinal direction** conducted on the composite sheet piles.

2 Test and material

This paper will present the results obtained from tensile tests conducted on composite sheet piles that were cut in the longitudinal direction. The testing procedure follows the guidelines outlined in ASTM D3039-2017. The dimensions for the longitudinal tensile test were determined based on NEN-EN-ISO 527-4 standards. It's worth noting that ASTM D3029-2017 employs a rectangular sample shape, whereas NEN-EN-ISO 527-4 uses widened ends on the sample where it's held. This design choice is advantageous as it encourages the sample to fail within the gauge section rather than where it is gripped. The material was tested both in the direction of the fibres (longitudinal) and perpendicular to them (transverse), but this report specifically focuses on the longitudinal tests.

These sheet piles are constructed from pultruded glass fibre polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

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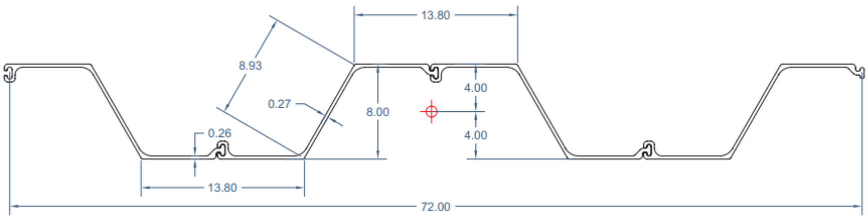

Figure 2-1 Superloc Series 1580

The glass fibre volume concentration is approximately 50%, comprising:

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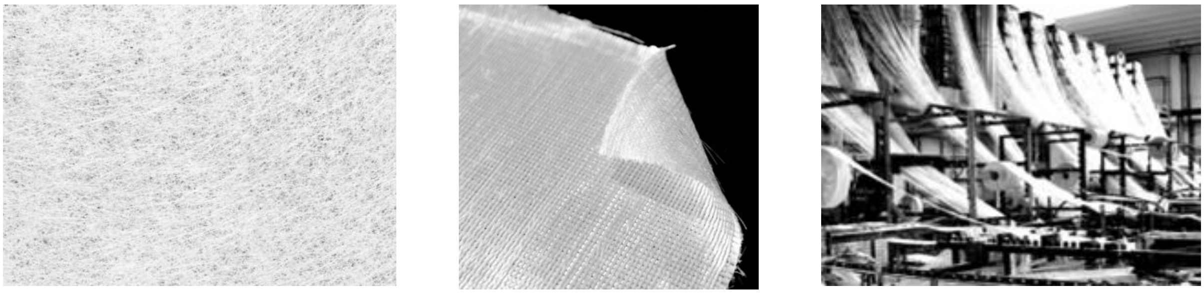


Continuous Filament 0/90 Fabric 0 Direction

Figure 2-2 Visual representation glass fibres used

3 Preparation and equipment used

The dimensions of the specimens were obtained from NEN-EN-ISO 527-4, as indicated in Table 3-1. It's important to note that these NEN-EN-ISO 527-4 dimensions were chosen over ASTM dimensions, as explained in the introduction of this paper. Appendix 1 provides the sawing plan for the samples extracted from the sheet pile elements. In this test, only the samples labelled 'TLxx' are relevant.

The specimens were prepared using waterjet cutting at the Equipment and Prototype Centre of the Technical University in Eindhoven. The location from which the samples were taken from the sheet pile is illustrated in Figures 8-2 and 8-3 in Appendix A. No specific consolidation methods were applied afterward, and the samples were stored in the test lab. Furthermore, no non-destructive test methods were conducted prior to this test.

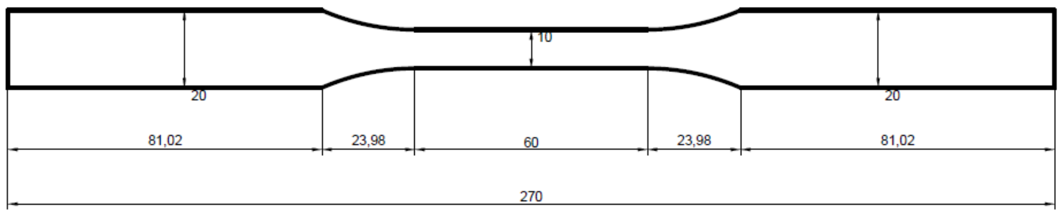
TLxx	

Table 3-1: Sample dimensions

For this test, an Instron 5985 machine manufactured on May 15, 2014, with a capacity of 250kN was utilized. The machine underwent its most recent calibration on February 14, 2022, by NMI Certin. Data was directly collected from the Instron machine using Bluehill Universal computer software to measure the material strain. The data was then exported as CSV files, which were subsequently imported into Excel for data processing.

To measure the material strain, we employed the Instron video extensometer AVE2, which had been calibrated prior to the test. This video extensometer recorded the extension across 2 white dots positioned 50 mm apart on the gauge length of the samples. For determining the average cross-sectional dimensions of the samples, we utilized a digital caliper capable of measuring up to 1/100th of a millimetre. The calibration date for the digital caliper is currently unknown.

The raw data collected for this study included the following types: Time, Force, Displacement, Tensile stress, and Axial strain. To input data into the computer software, we provided the Length, Thickness, and Width parameters. The Width and Thickness were measured at three different points along the gauge length of each sample, and the results are presented in Table 3-2.

Tensile longitudinal									
	Edge	Middle	Edge		Edge	Middle	Eedge		
Sample	Width (mm)	Width (mm)	Width (mm)	**Average width (mm)**	Thickness (mm)	Thickness (mm)	Thickness (mm)	**Average thickness (mm)**	**Average area (mm2)**
TL01	10,00	10,09	10,20	10,10	6,75	6,74	6,75	6,75	68,05
TL02	10,20	10,05	10,15	10,13	6,73	6,70	6,69	6,71	67,89
TL03	10,11	10,15	10,21	10,16	6,65	6,67	6,65	6,66	67,74
TL04	10,02	9,98	9,92	9,97	6,61	6,63	6,65	6,63	66,12
TL05	9,98	9,97	10,00	9,98	6,62	6,63	6,70	6,65	66,19
TL06	10,05	10,07	10,09	10,07	6,55	6,58	6,55	6,56	66,26
TL07	10,04	10,03	10,05	10,04	6,67	6,67	6,64	6,66	66,97
TL08	10,02	10,06	10,05	10,04	6,66	6,69	6,66	6,67	67,19
TL09	9,98	10,00	9,98	9,99	6,61	6,62	6,64	6,62	66,11
TL10	10,10	10,01	10,01	10,04	6,64	6,62	6,66	6,64	66,46
TL11	10,02	10,1	10,04	10,05	6,68	6,70	6,66	6,68	67,36
TL12	10,03	10,02	10,03	10,03	6,70	6,69	6,71	6,70	67,08
TL13	10,06	10,04	10,06	10,05	6,68	6,68	6,66	6,67	67,16
TL14	9,99	10,02	10,02	10,01	6,70	6,66	6,65	6,67	66,67
TL15	9,99	9,99	9,99	9,99	6,52	6,49	6,47	6,49	64,84
TL16	9,98	10,03	10,03	10,01	6,57	6,62	6,63	6,61	66,29
TL17	10,02	10,03	10,01	10,02	6,72	6,72	6,69	6,71	67,33

Table 3-2: Measured longitudinal sample dimensions

A total of 13 tensile tests were conducted in the longitudinal direction of the material, with a testing speed set at 2 mm/min. To ensure proper alignment of the samples in the Instron machine, a system as depicted in Figure 3-1 was employed. It's worth noting the presence of stops designed to block the sample, guaranteeing alignment with the grips of the machine.

The samples were securely held in the Precision Manual Wedge Grips, model number 2716-030. It's important to mention that no tabs were utilized during testing, as they were deemed unnecessary given that the failure results aligned with our initial expectations in the initial tests.

The standard laboratory conditions throughout the testing period maintained a relative humidity (RH) of 40-50% and a temperature of approximately 21 degrees Celsius. No additional environmental-specific conditions were applied during the tests or the storage of the samples.

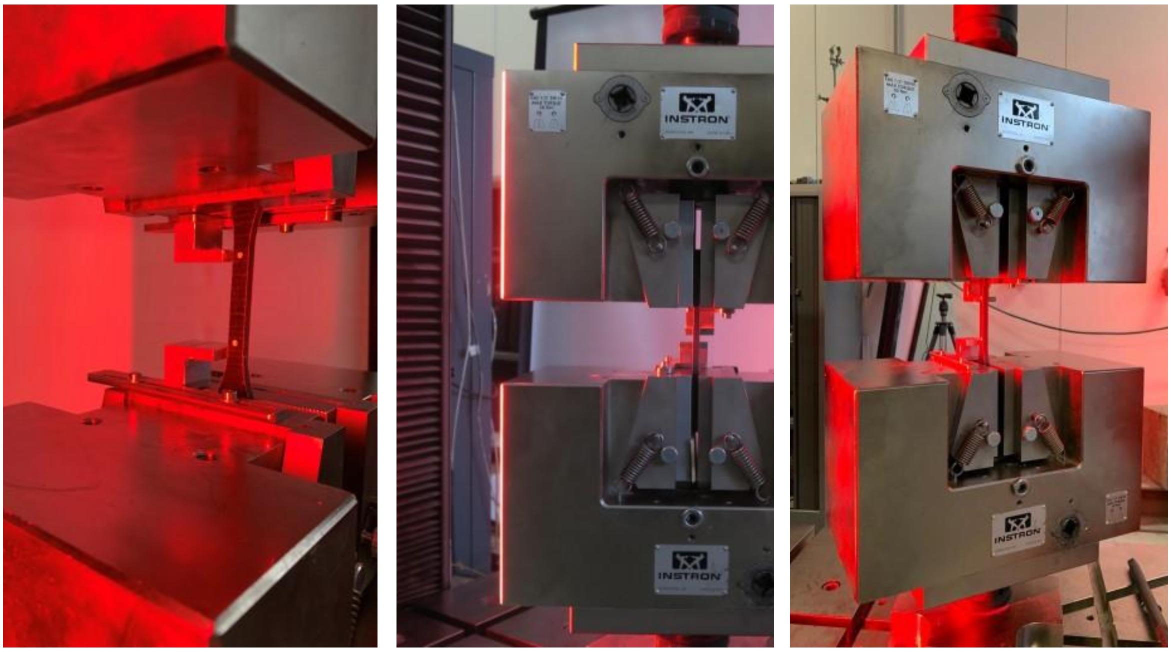


Figure 3-1 Sample alignment in the machine

4 Results

Figures 4-1 and 4-2 display the force-versus-displacement curves for the tests conducted. Table 4-1 provides the stress/strain graphs for each sample in the longitudinal direction. Please note that TL010 and TL015 have been excluded from the analysis due to incorrect attachment in the testing machine, which led to skewed results as evident in Figure 4.

Figure 5 presents the same force-versus-displacement graphs with outliers filtered out. However, it's important to highlight that sample TL010 still indicates a genuine yielding load, even after outlier removal.

For samples TL016 and TL017, they cannot be used in the calculations for maximum strain due to a measurement error in the strain data, as evident in the graphs presented in Table 4-1.

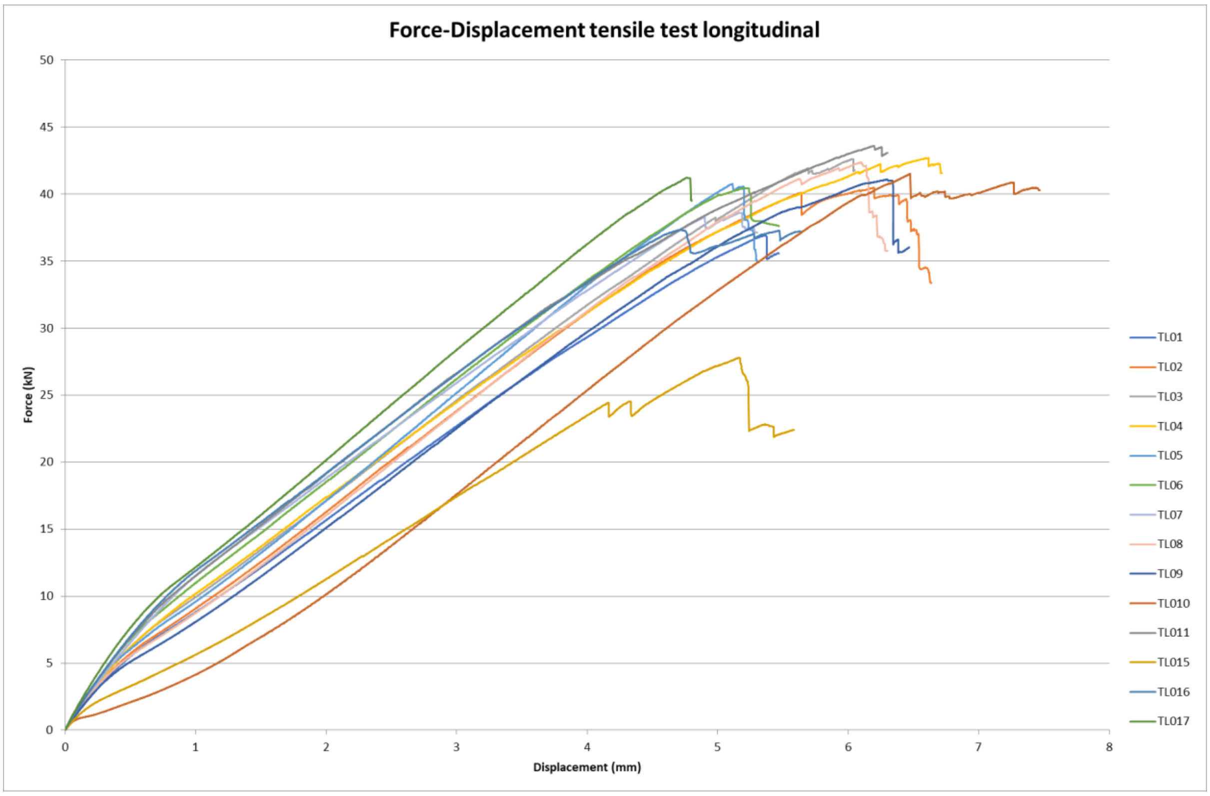


Figure 4-1 Force-displacement of the tensile test in longitudinal direction

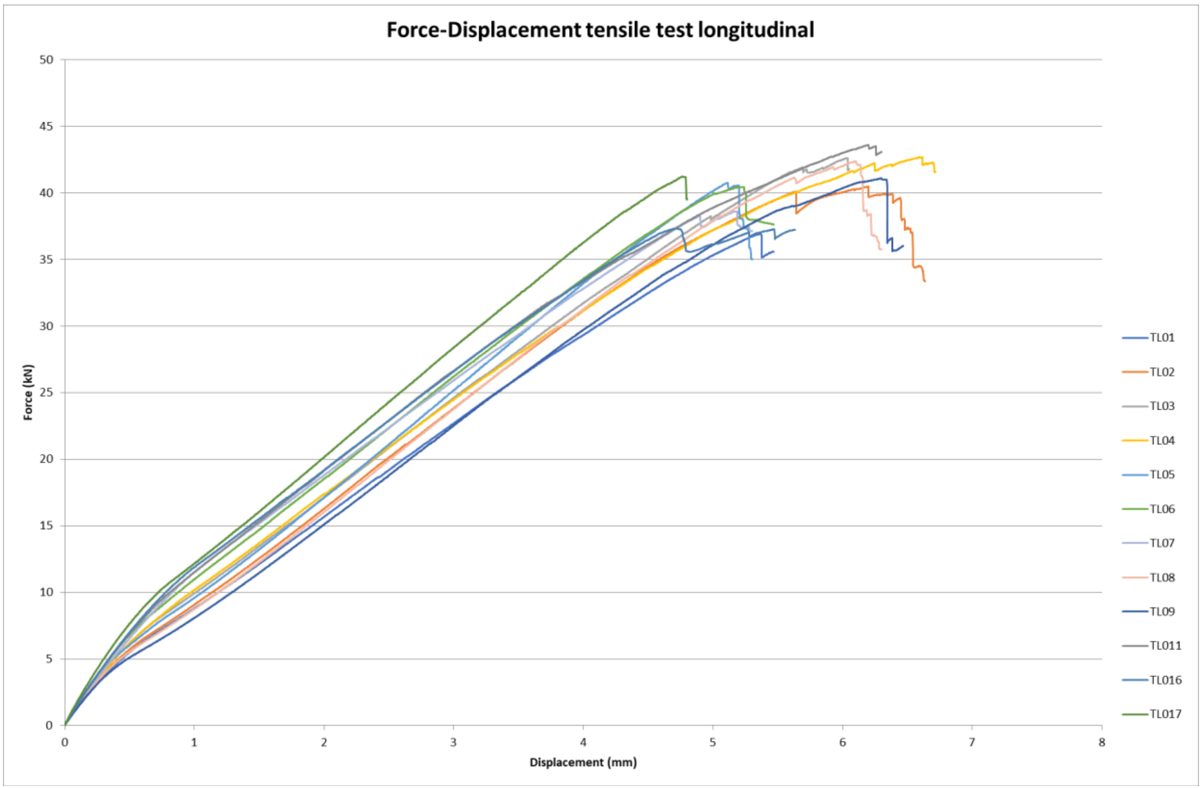
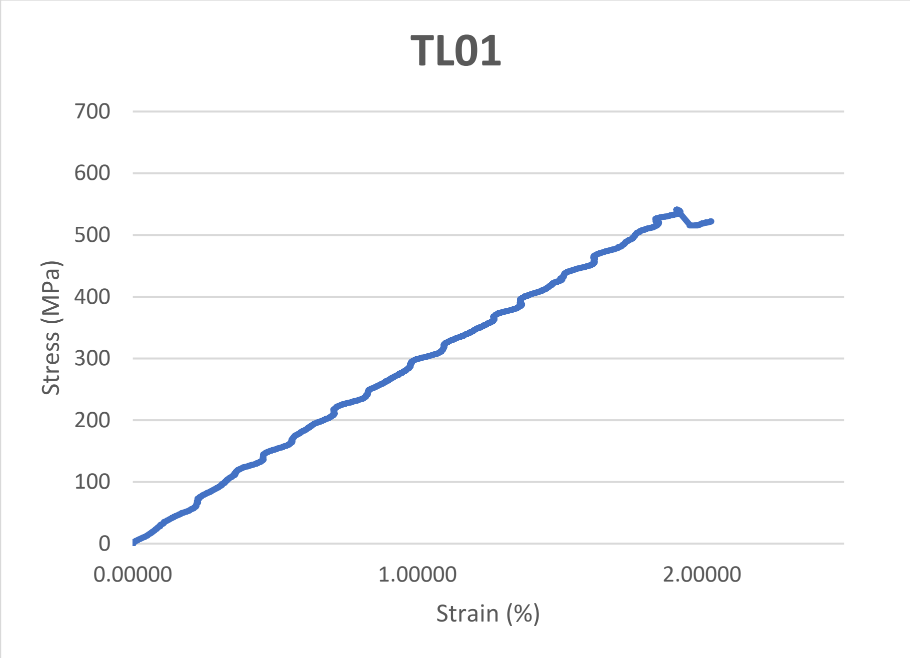
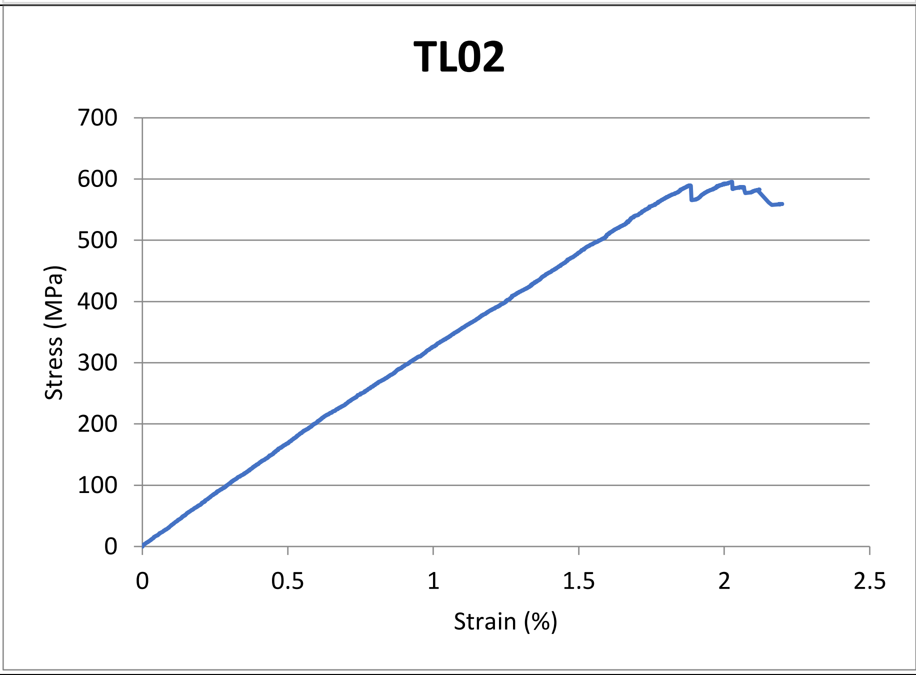
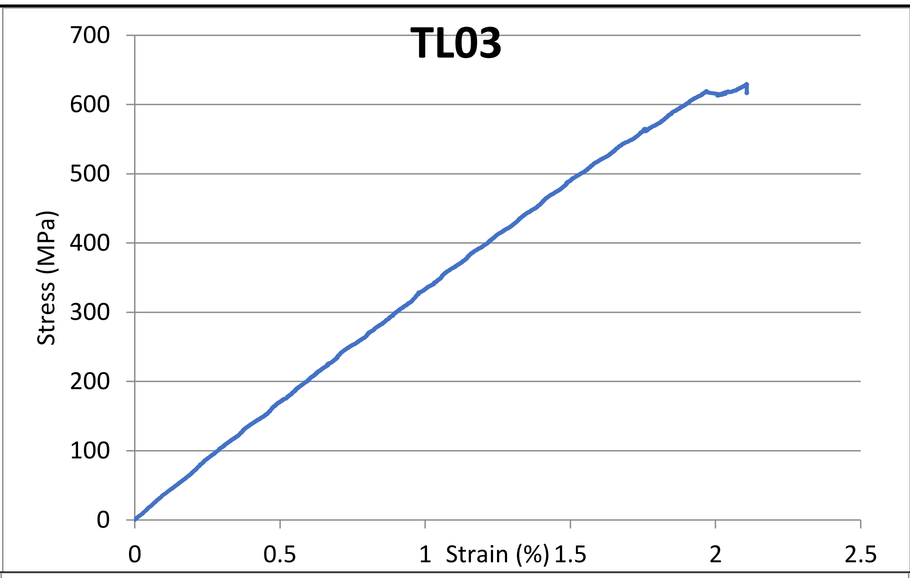
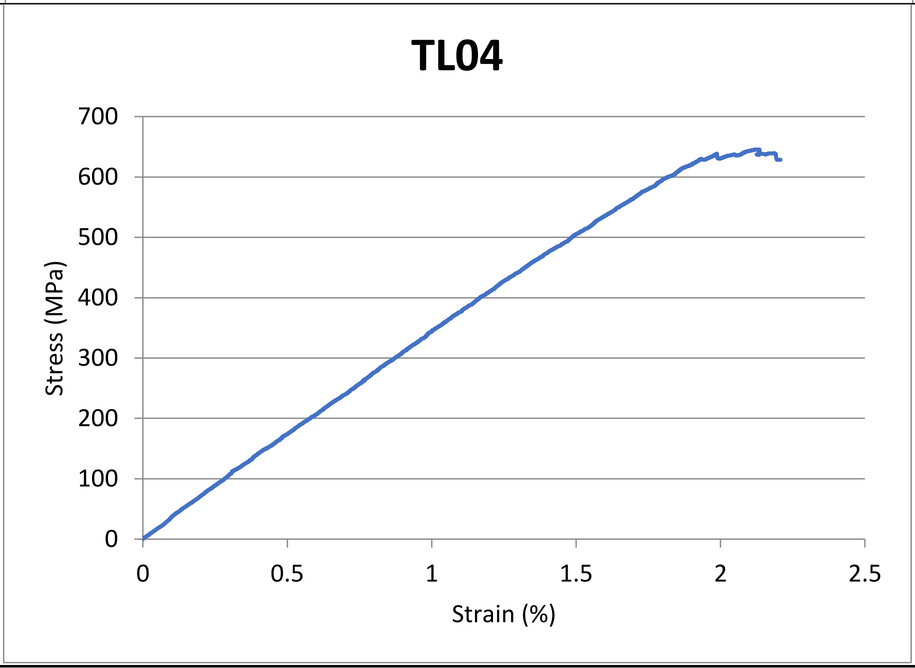
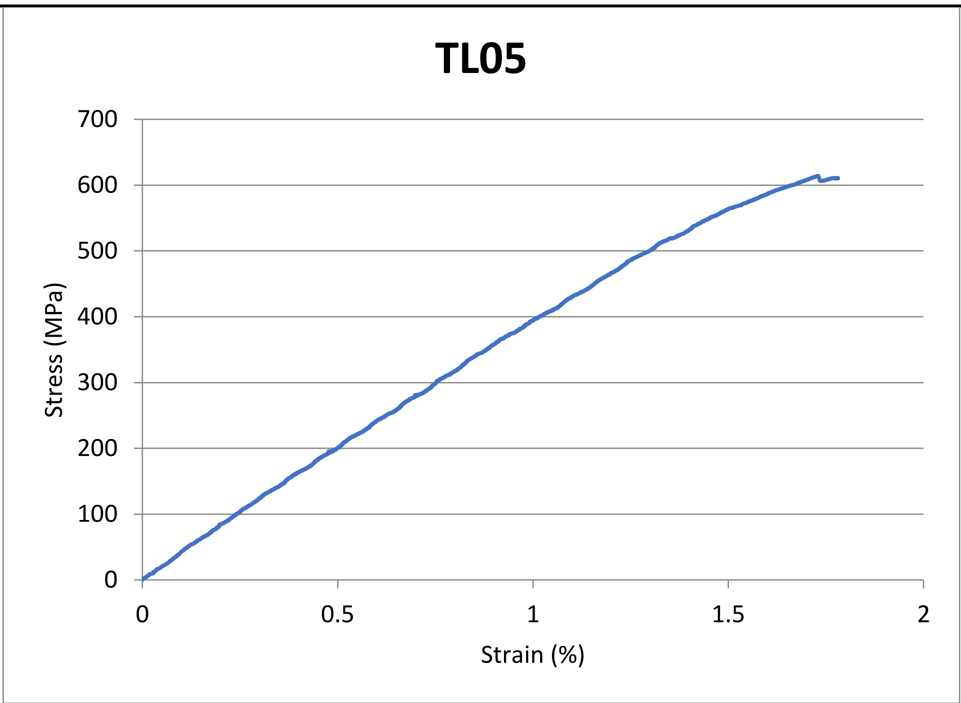
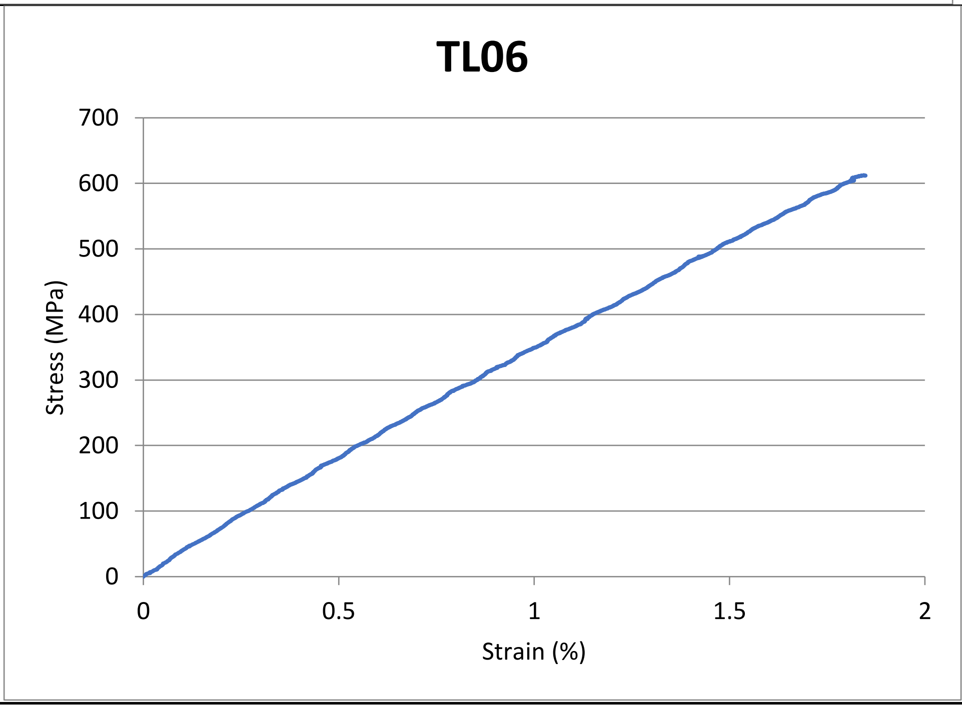
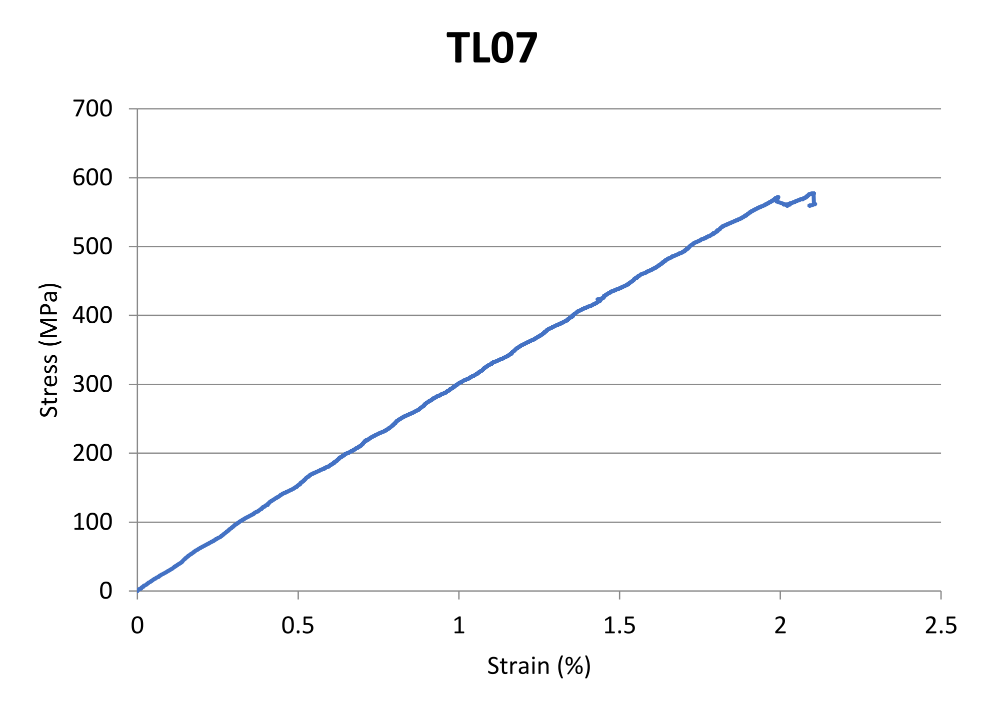
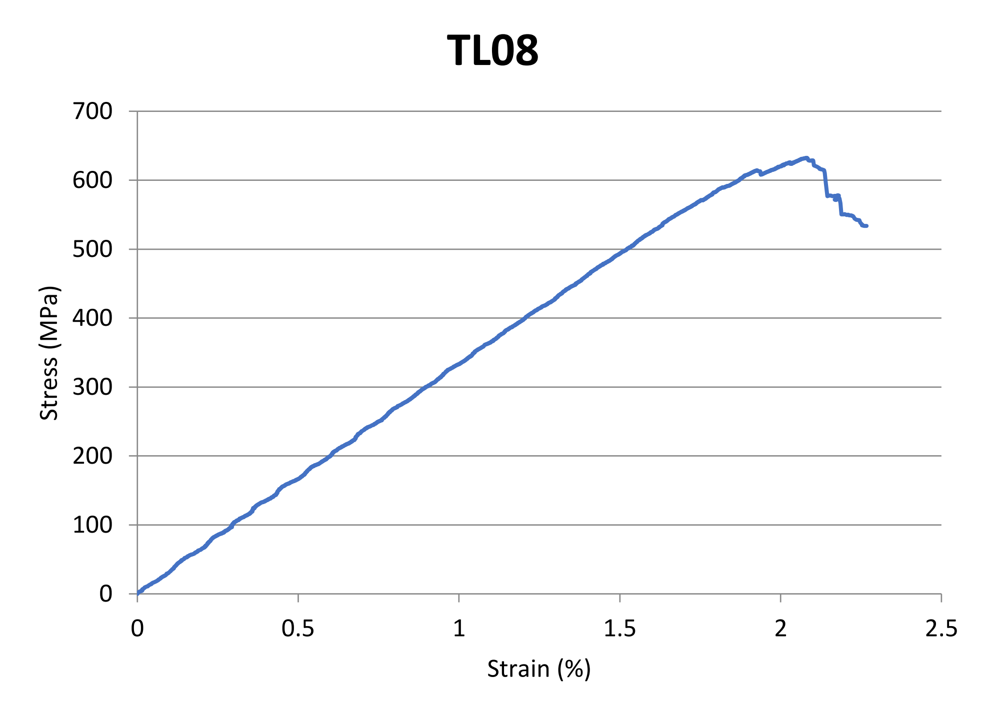


Figure 4-2 Force displacement of the tensile test in longitudinal direction - corrected

Test:	Stress/strain graph
TL 01	
TL 02	

TL 03	TL03 Stress (MPa) Strain (%) 0 100 200 300 400 500 600 700 0.5 1 1.5 2 2.5	
TL 04	TL04 Stress (MPa) Strain (%) 0 100 200 300 400 500 600 700 0.5 1 1.5 2 2.5	

TL 05	TL05 700 600 500 400 300 200 100 0 Stress (MPa) 0 0.5 1 1.5 2 Strain (%)	
TL 06	TL06 700 600 500 400 300 200 100 0 Stress (MPa) 0 0.5 1 1.5 2 Strain (%)	

TL 07	TL07 Stress (MPa) 700 600 500 400 300 200 100 0 0 0.5 1 1.5 2 2.5 Strain (%)	
TL 08	TL08 Stress (MPa) 700 600 500 400 300 200 100 0 0 0.5 1 1.5 2 2.5 Strain (%)	

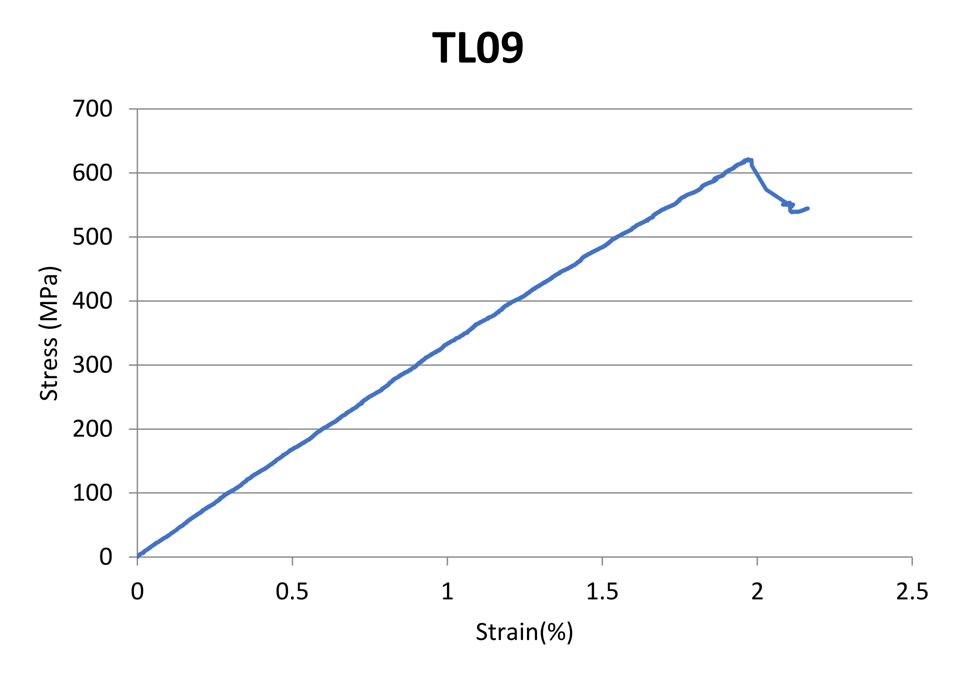
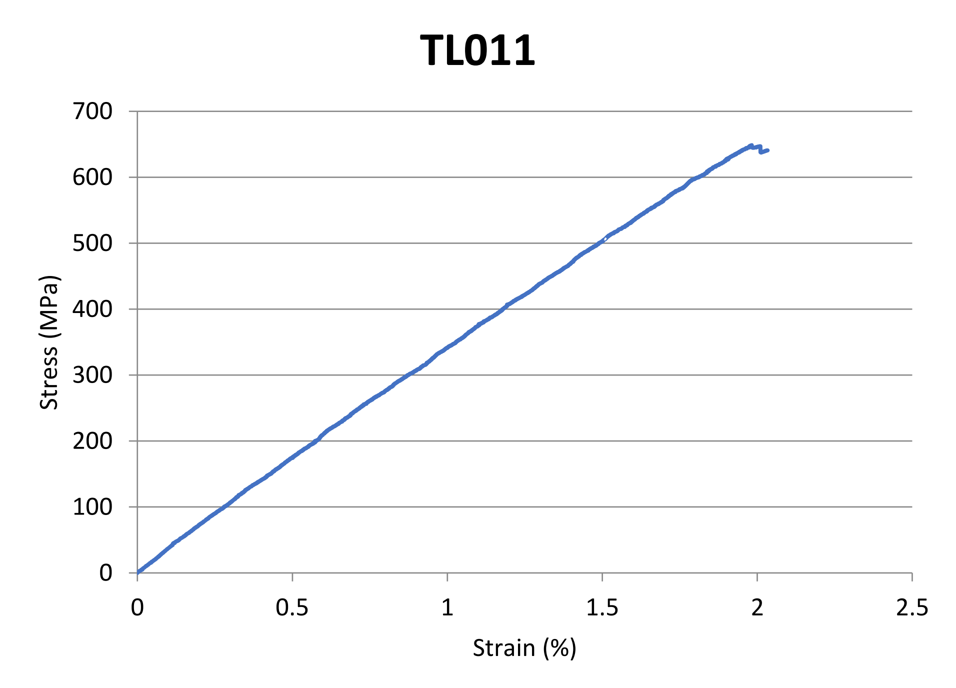
TL 09	
TL 11	

Table 4-1: Stress/strain diagrams

5 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value
n = number of tests
V_x = Which is the coefficient of variation $V_x = S_x/m_x$
S_x = Standard deviation
m_x = average value
k_n = Static factor which can be calculated with $k_n = K* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.
K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 5-1: k_n values

6 Longitudinal tensile strength

6.1 Ultimate tensile strength and stress

Table 6-1 presents the ultimate tensile strength and stress values for each specimen tested in the longitudinal direction of the material. It's important to note that sample TL010 and TL015 have been excluded from the table because of their incorrect attachment in the mechanical grips, which would have led to inaccurate calculations and skewed results.

Individual Strength and Stress

Sample	Max Force (kN)	Deviation (kN)	Max Stress (MPa)	Deviation (MPa)
TL01	36.91	-3.78	541.3	-66.64
TL02	40.46	-0.22	595.2	-12.73
TL03	42.60	1.92	629.6	21.62
TL04	42.68	2.00	645.7	37.75
TL05	40.75	0.07	612.3	4.29
TL06	40.45	-0.24	612.3	4.29
TL07	38.61	-2.07	577.5	-30.50
TL08	42.36	1.67	632.5	24.51
TL09	41.08	0.40	621.2	13.21
TL011	43.60	2.92	648.9	40.89
TL016	37.44	-3.24	565.8	-42.14
TL017	41.24	0.56	613.4	5.44
Average (kN)	40.68	Average (MPa)	608.0	
Standard deviation (kN)	2.104	Standard deviation (MPa)	32.64	
Coefficient of variation (%)	5%	Coefficient of variation (%)	5%	
Coefficient of variation	0.05171	Coefficient of variation	0.05368	
K	1.645	K	1.645	
kn	1.71	kn	1.71	
n	13	n	13	
Rk (kN)	37.09	Rk (MPa)	552.3	

Table 6-1: Individual strength and stress longitudinal direction

6.2 Strain at failure

Table 6-2 displays the strain at failure for the tensile tests conducted in the longitudinal direction. However, please be aware that TL010, TL015, TL016, and TL017 have been excluded from this table for specific reasons:

1. TL016 and TL017 were removed due to measurement issues with the video extensometer, which impacted the reliability of the data.
2. TL010 and TL015 were omitted from this calculation because these samples were not inserted correctly into the Instron machine, resulting in distorted test results.

Individual Strain at failure

Sample	Strain (%)	Deviation (%)
TL01	1.91	0.079
TL02	2.03	0.199
TL03	2.11	0.279
TL04	2.12	0.289
TL05	1.73	-0.101
TL06	1.84	0.009
TL07	2.1	0.269
TL08	2.08	0.249
TL09	1.97	0.139
TL011	1.98	0.149
Average (%)	1.99	
Standard deviation (%)	0.129	
Coefficient of variation (%)	6%	
Coefficient of variation	0.0650	
K	1.645	
kn	1.73	
n	10	
Rk (%)	1.76	

Table 6-2: Individual Strain longitudinal

6.3 E-Modulus and

Table 6-3 presents the data utilized for calculating the E-Modulus in the longitudinal direction of the material. The E-Modulus calculations are based on the 0.1% to 0.3% strain interval, following the methodology outlined in ASTM D3039. It's worth noting that the following samples have been excluded from this calculation:

1. TL016 and TL017 due to issues with the video extensometer, which affected the accuracy of the strain measurements.

2. TL010 and TL015 because of their slanted insertion, which could have introduced errors into the results.

E-Modulus									
	Strain			Stress			E-Modulus	Deviation
Sample	0.1%	0.3%	delta(-)	0.1%	0.3%	delta (MPa)	(MPa)	(MPa)
TL01	0.0010132	0.0030021	0.0019889	31.2395	91.4147	60.1752	30255.5	-4369
TL02	0.0010015	0.0029975	0.0019960	34.881	102.7828	67.9018	34018.9	-606
TL03	0.0010019	0.0029996	0.0019977	36.6363	104.5322	67.8959	33987.0	-638
TL04	0.0009997	0.0029995	0.0019998	37.0979	107.1469	70.049	35028.0	403
TL05	0.0010025	0.0029974	0.0019949	42.7826	123.7702	80.9876	40597.3	5972
TL06	0.0010009	0.0029991	0.0019982	40.7918	111.6072	70.8154	35439.6	815
TL07	0.0009960	0.0030003	0.0020043	30.2178	95.0371	64.8193	32340.1	-2285
TL08	0.0009986	0.0030003	0.0020017	31.5753	102.6915	71.1162	35527.9	903
TL09	0.0010021	0.0030004	0.0019983	33.5465	102.1593	68.6128	34335.6	-289
TL011	0.0010059	0.0029996	0.0019937	37.7173	106.9362	69.2189	34718.8	94
						Average (MPa)	34624.9	
						Standard deviation (MPa)	2635.02	
						Coefficient of variation (%)	8%	
						Coefficient of variation	0.0761018	
						K	1.645	
						kn	1.725	
						n	10	
						Rk (MPa)	30079	

Table 6-3: Individual Strain longitudinal

6.4 Failure mode

In the case of the samples cut in the longitudinal direction of the material, it's notable that all specimens exhibited a uniform failure mechanism. The specimens initially began delaminating along their edges in the middle of the gauge length, eventually leading to delamination across the entire gauge width. According to the ASTDM D3039 classification, this failure mechanism corresponds to DGM, as illustrated in Figure 6-1. Further visual documentation of all the failed specimens can be found in Figure 6-2.

Figure 6-1 Failure mechanism DGM

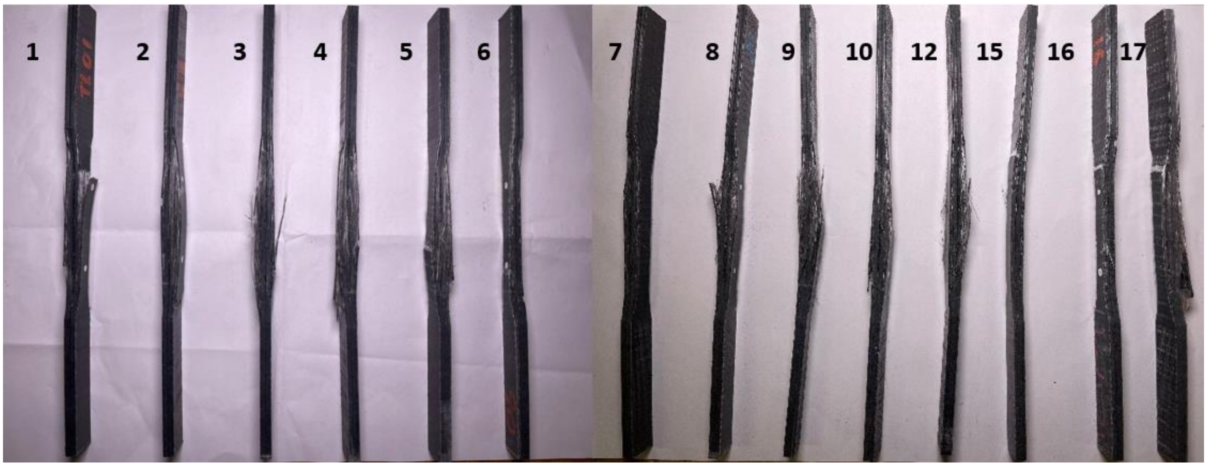


Figure 6-2 Failure mechanism longitudinal

7 Summary

In summary, the results obtained from the tensile tests yield the following findings, as presented in Table 7-1.

Results tensile strength longitudinal direction	
Characteristic Strength	37.09 kN
Characteristic Stress	552.3 MPa
Characteristic Maximal Strain	1.76%
Characteristic E-Modulus	30079 MPa

table 7-1 Material properties according to tensile test

8 Appendix

8.1 Appendix A – Sample numbering

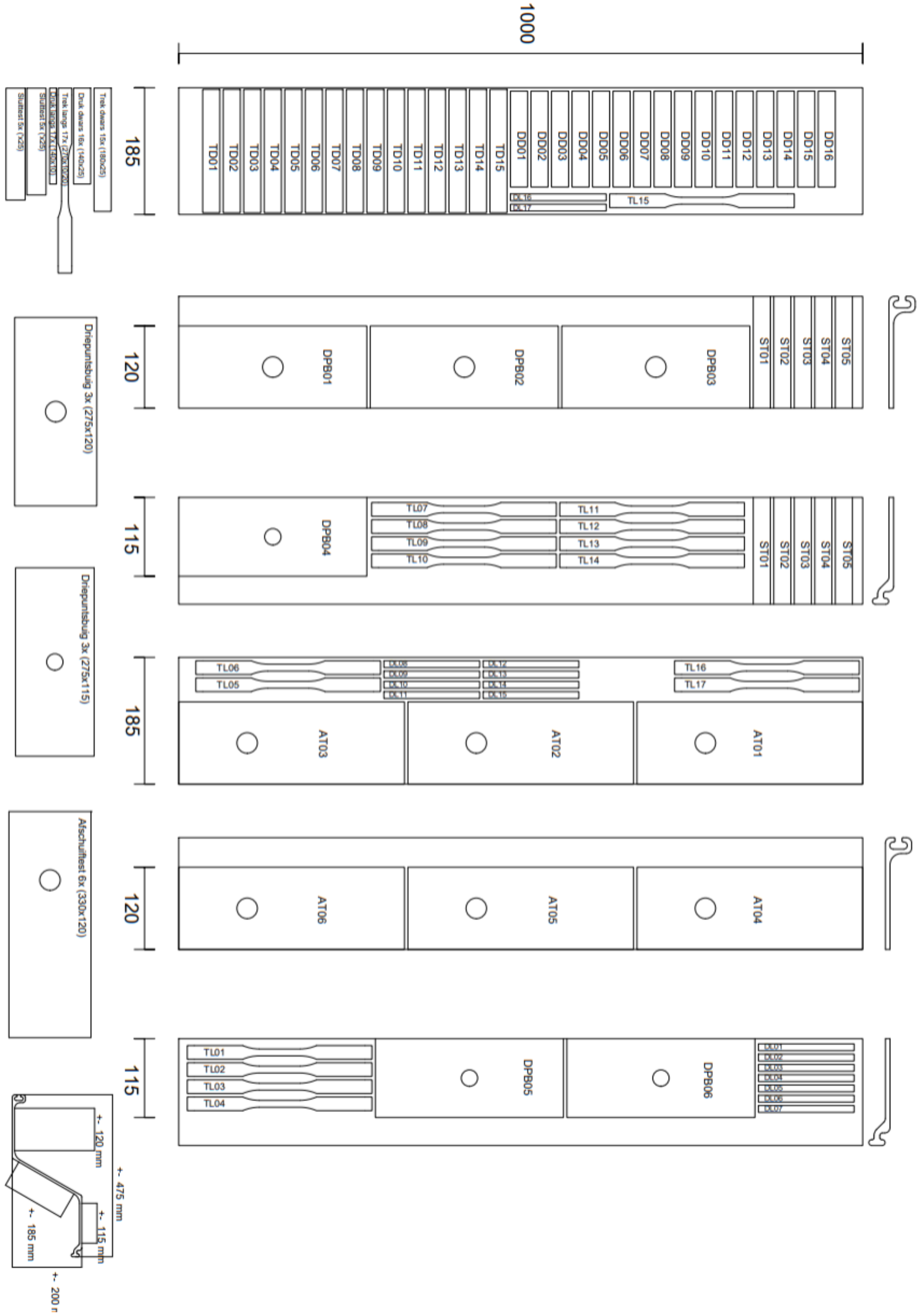


Figure 8-1 Saw plan all samples

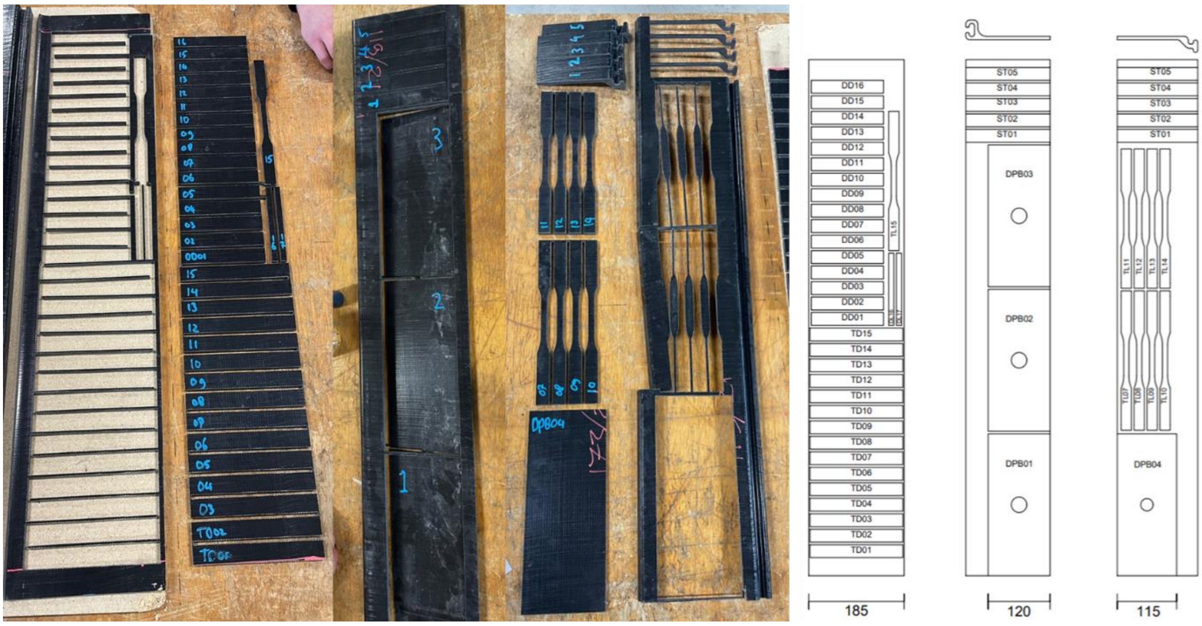


Figure 8-2 Samples retrieved from sheet

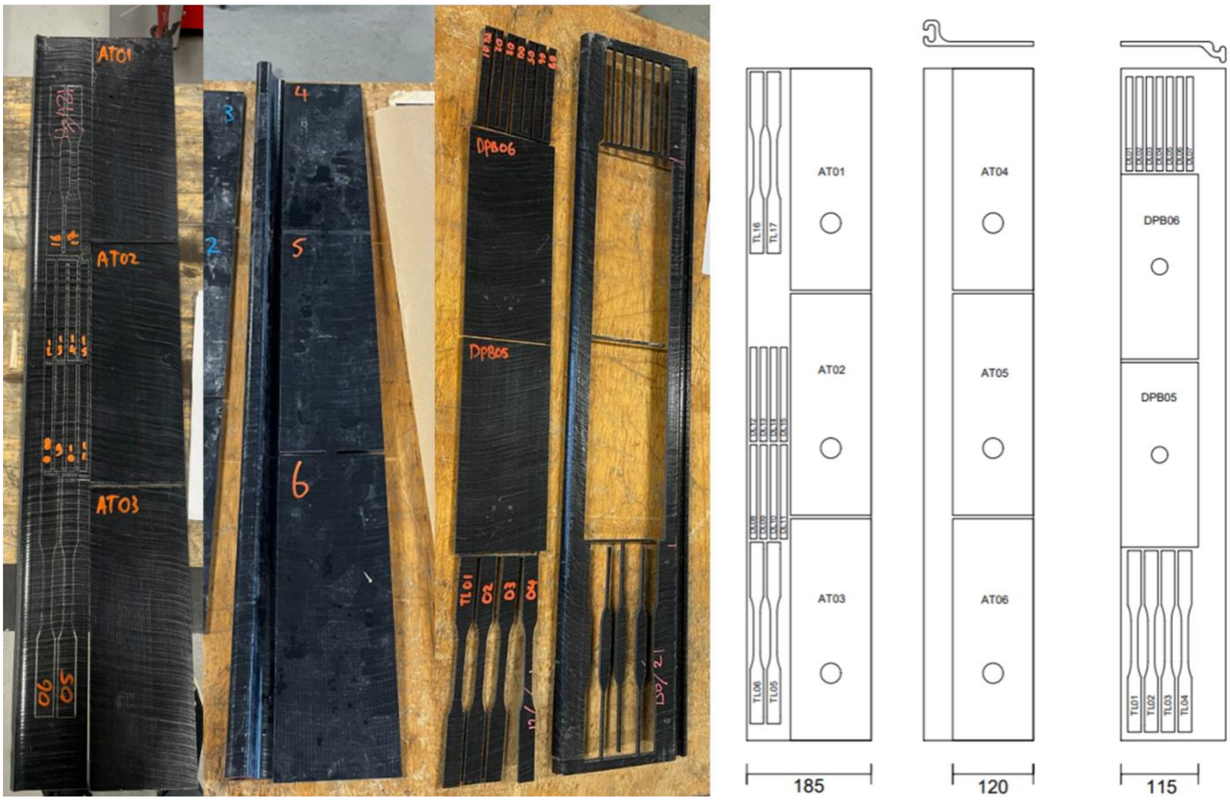
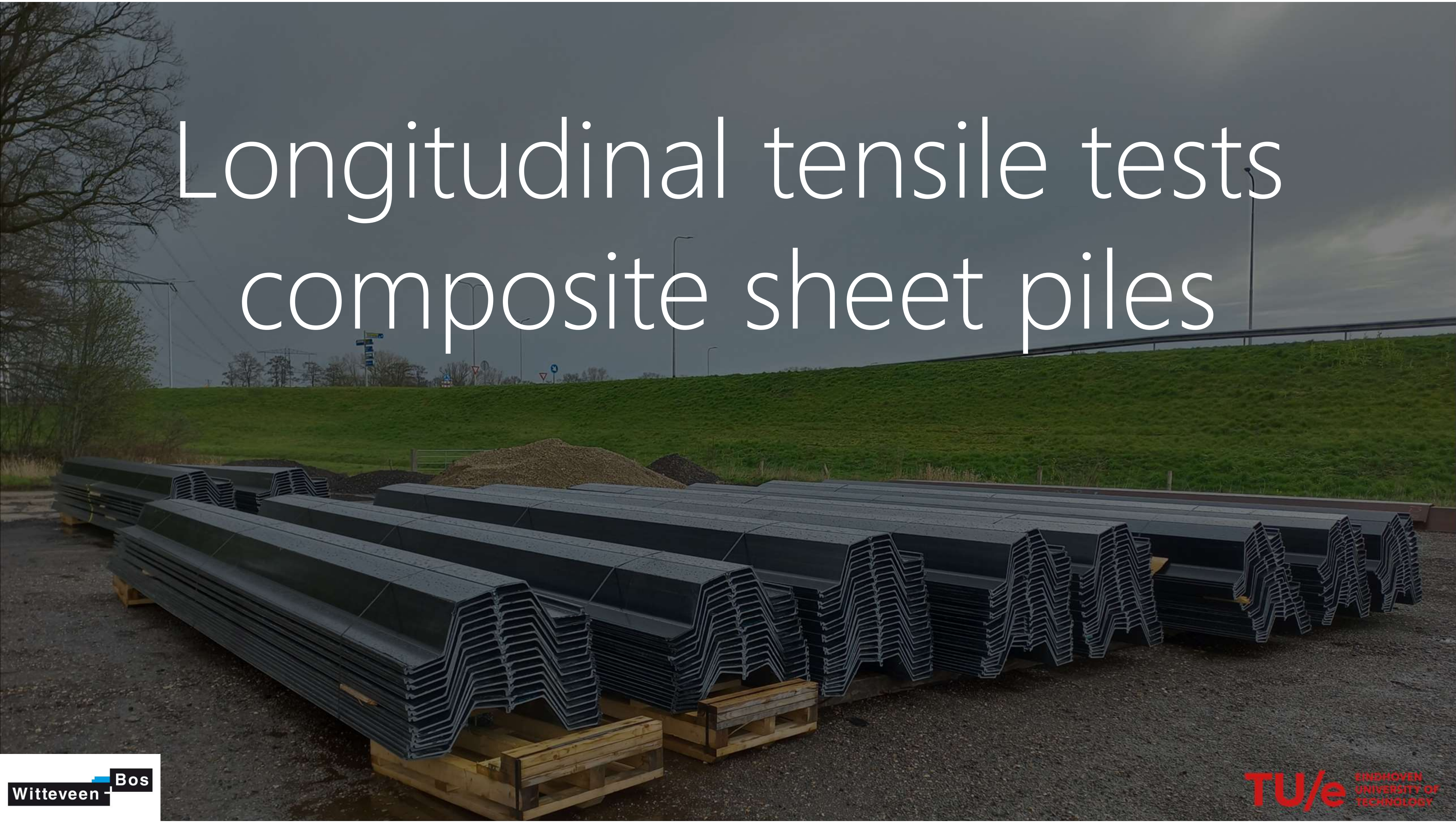


Figure 8-3 Samples retrieved from sheet

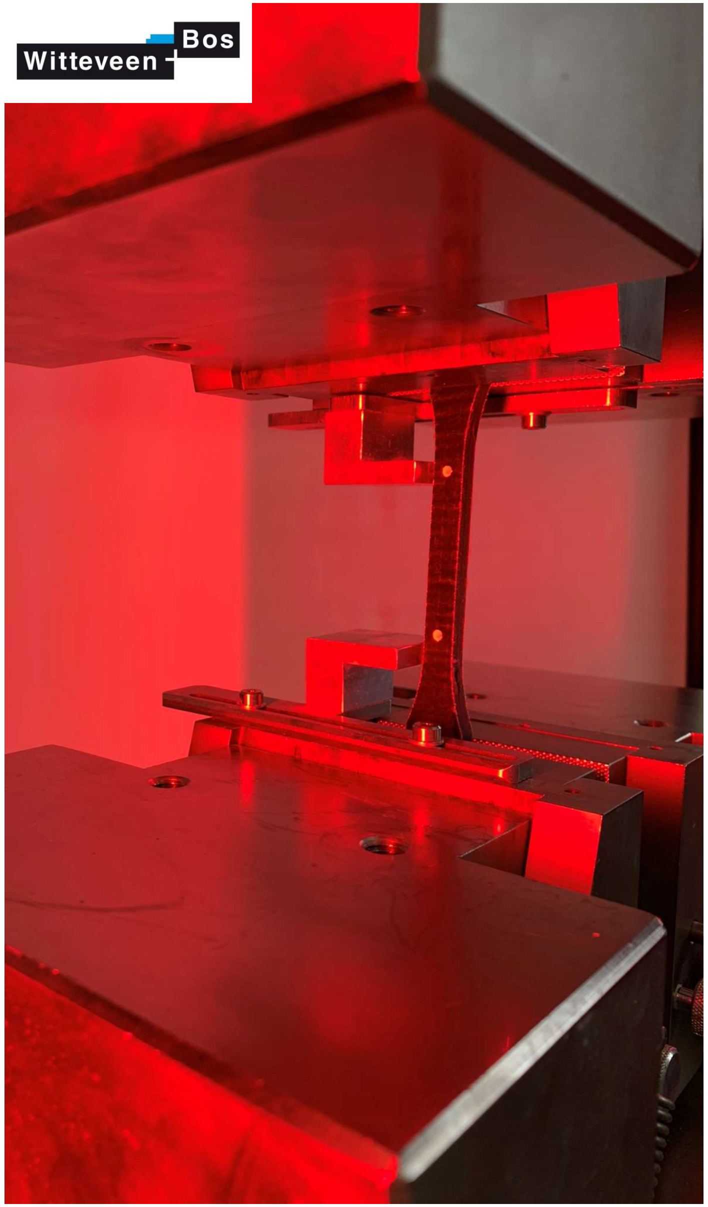
8.2 Appendix B – Presentation results and test

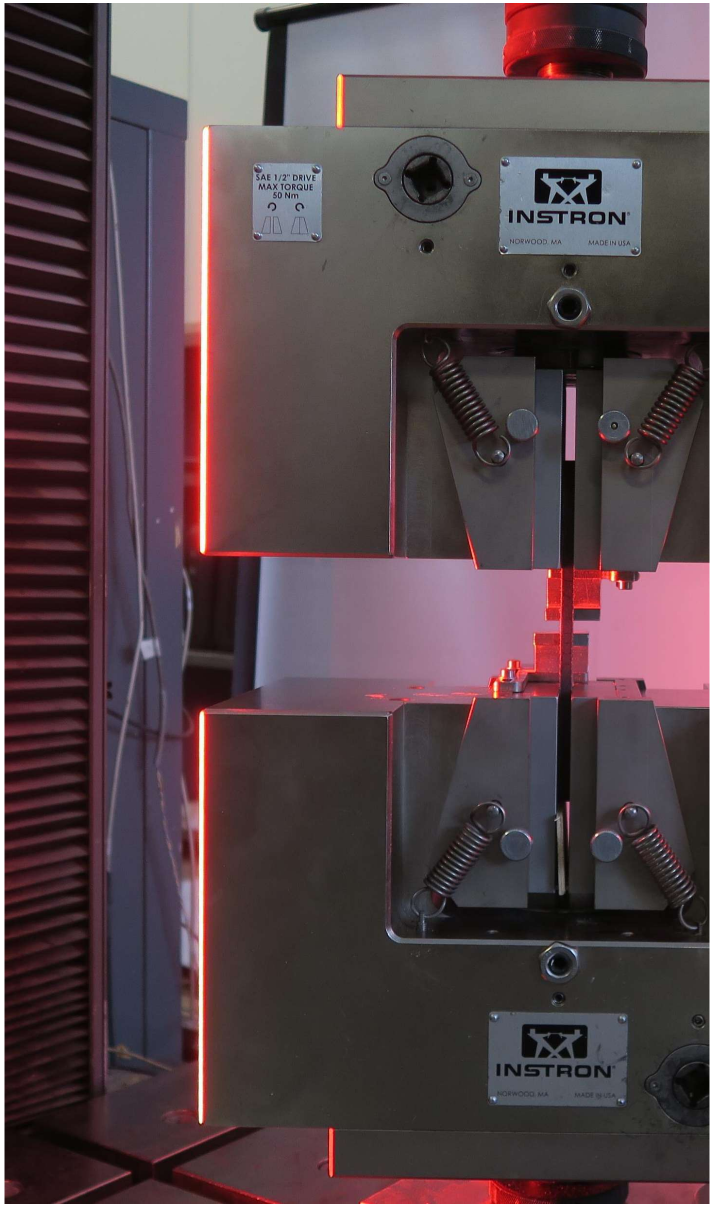
Longitudinal tensile tests composite sheet piles



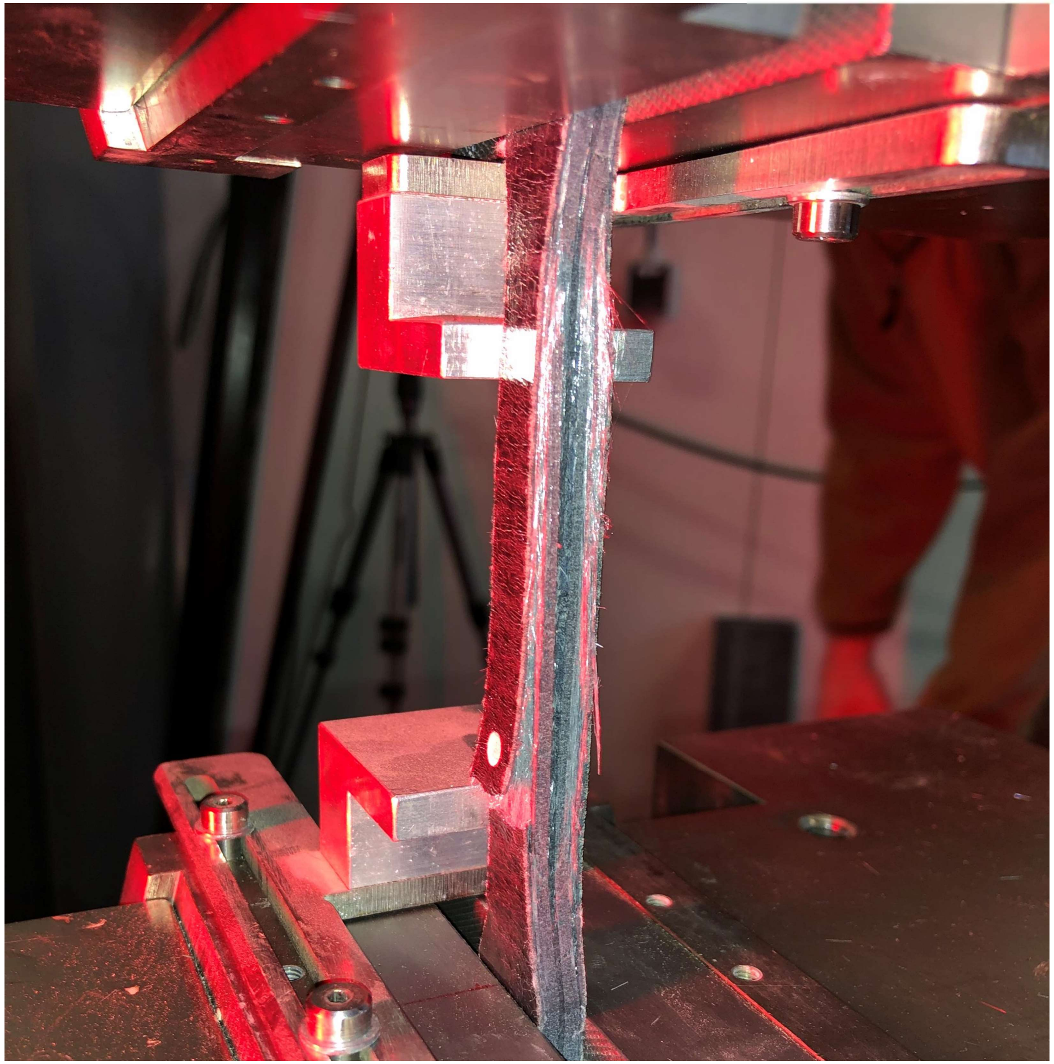
Witteveen + Bos

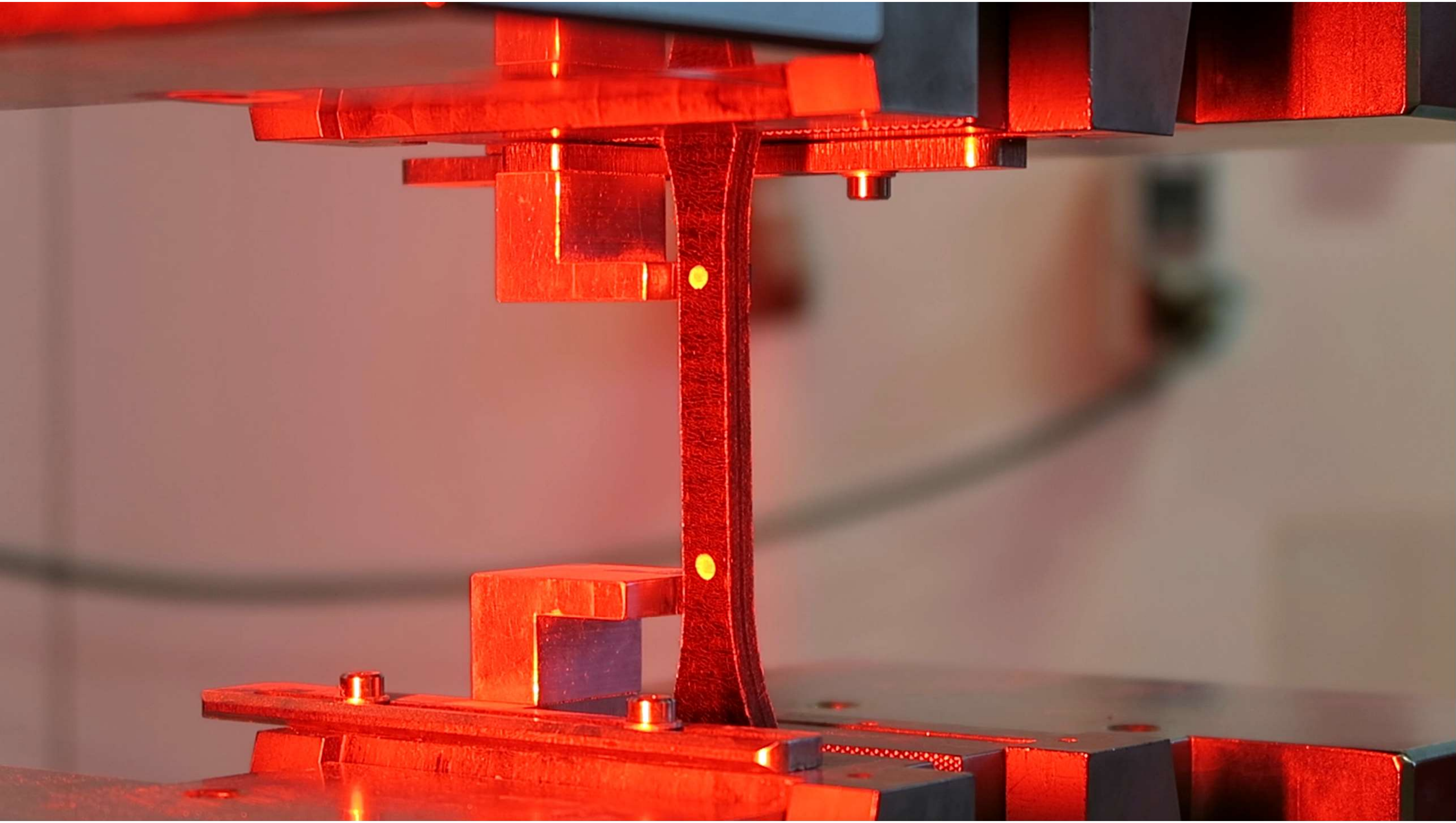
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

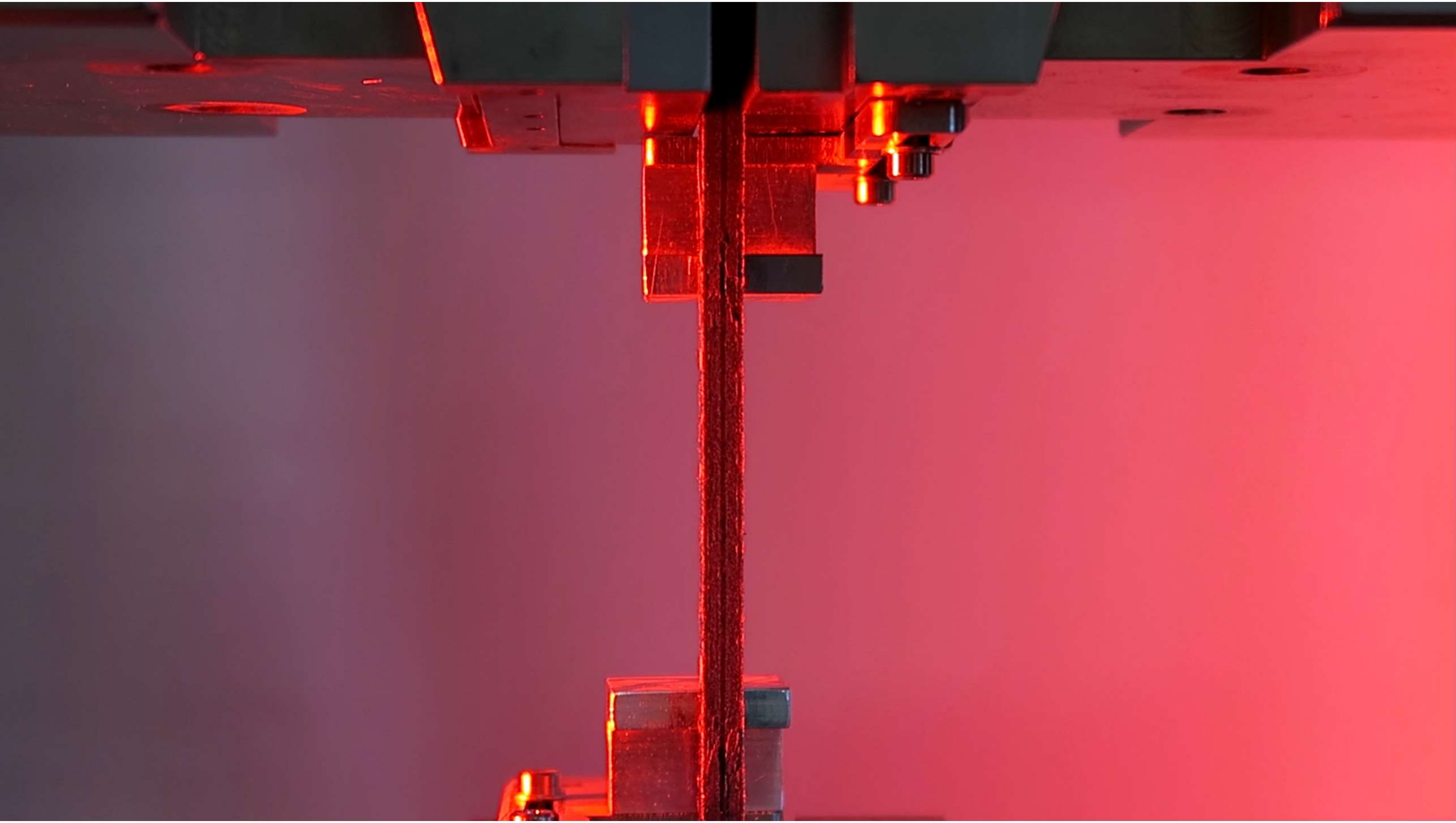

Witteveen+Bos

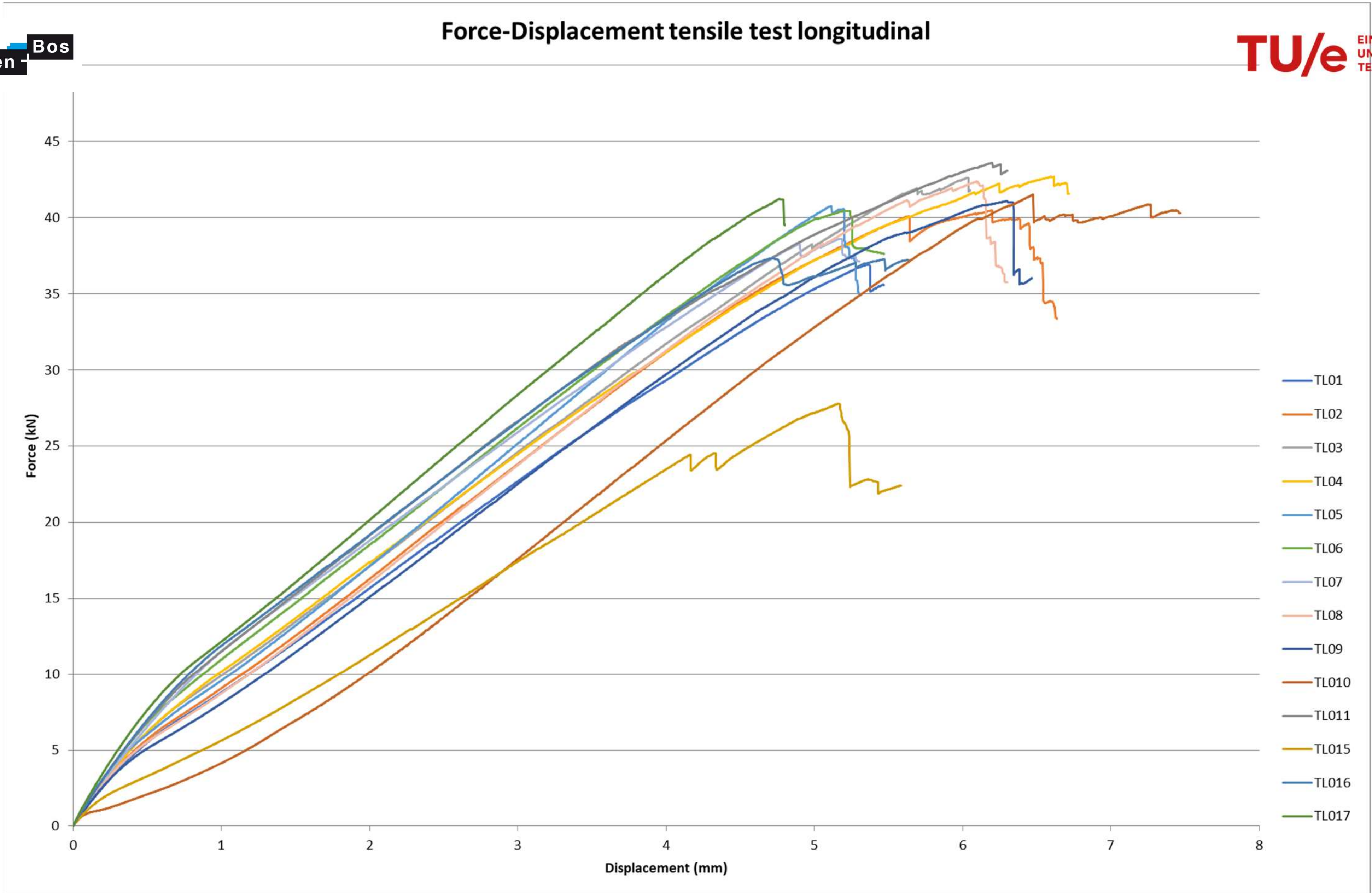

SAE 1/2" DRIVE
MAX TORQUE
50 Nm
INSTRON
NORWOOD, MA
MADE IN USA
INSTRON


TU/e
EINDHOVEN
UNIVERSITY OF
TECHNOLOGY
INSTRON
INSTRON








Force-Displacement tensile test longitudinal
Force (kN)
Displacement (mm)
0
5
10
15
20
25
30
35
40
45
0
1
2
3
4
5
6
7
8
TL01
TL02
TL03
TL04
TL05
TL06
TL07
TL08
TL09
TL010
TL011
TL015
TL016
TL017

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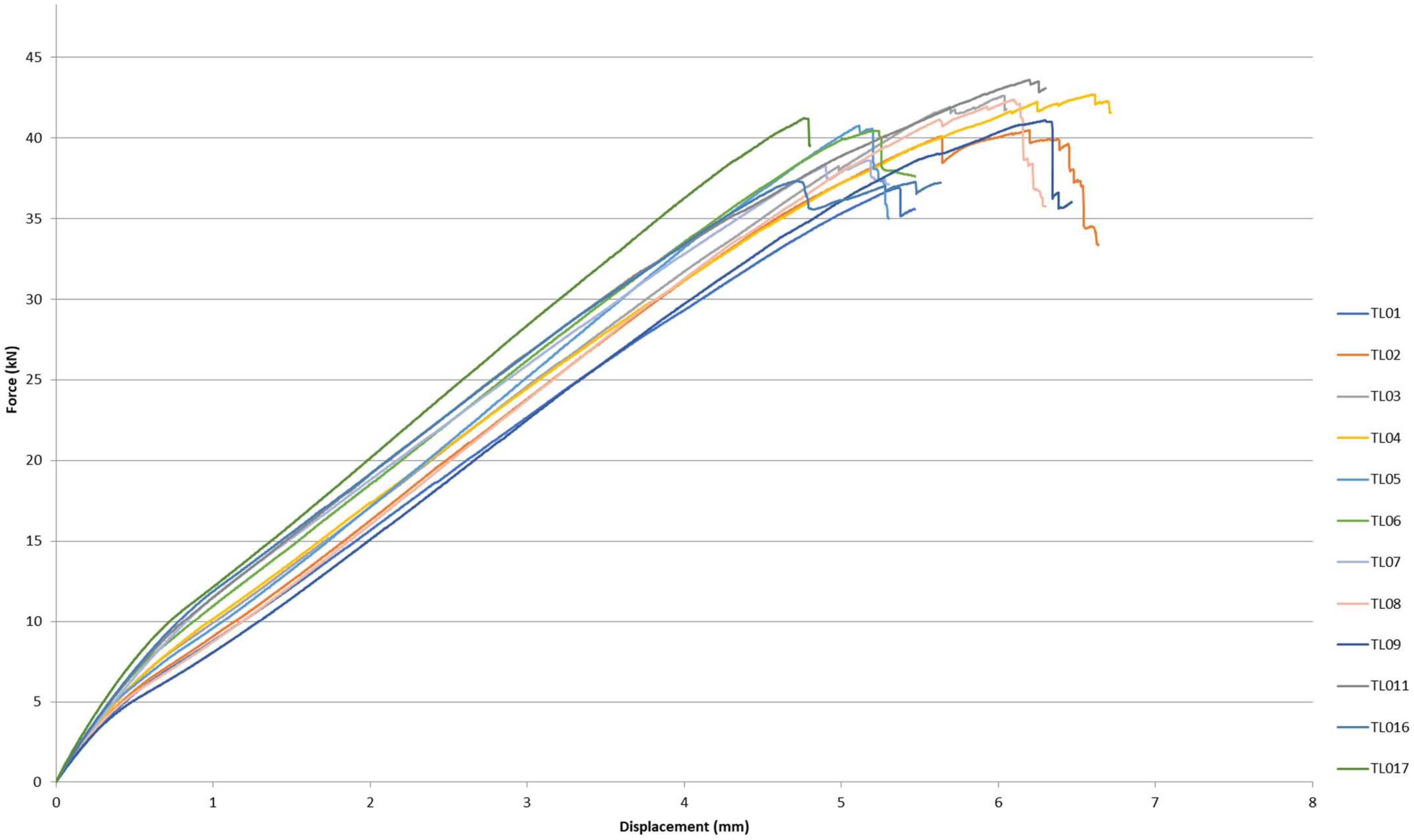
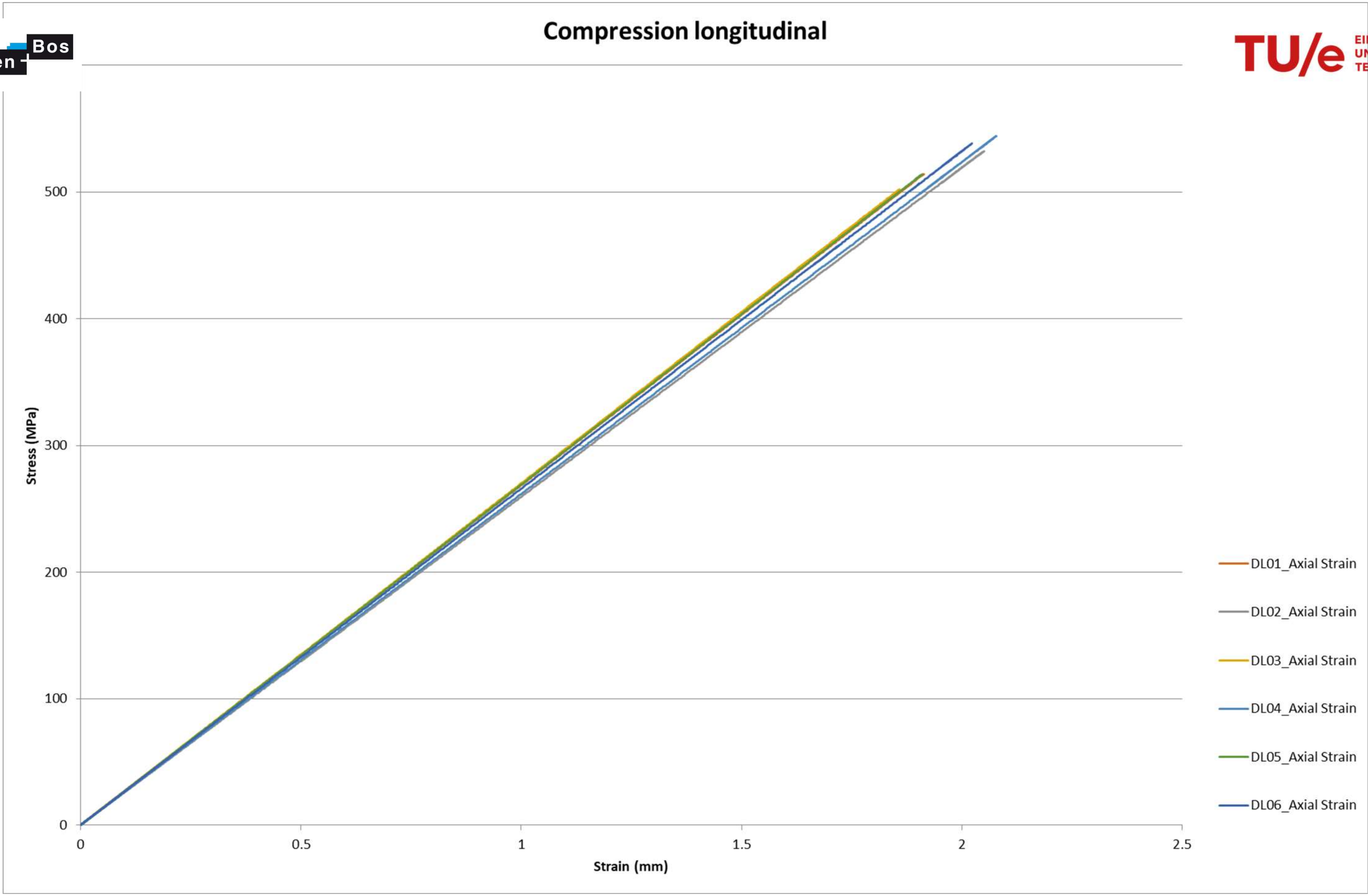
Force-Displacement tensile test longitudinal

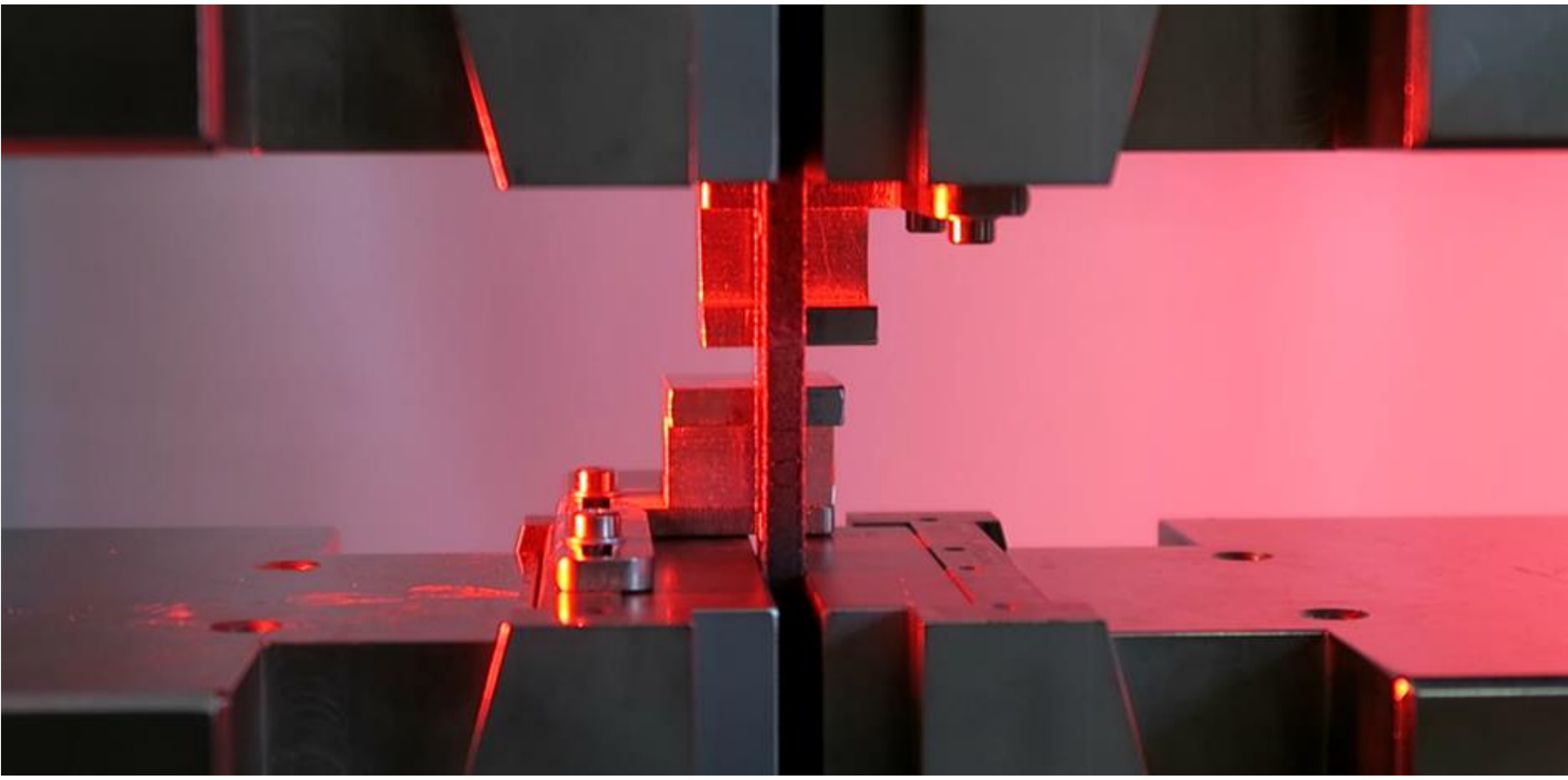



Compression longitudinal
Stress (MPa)
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
Strain (mm)
DL01_Axial Strain
DL02_Axial Strain
DL03_Axial Strain
DL04_Axial Strain
DL05_Axial Strain
DL06_Axial Strain

5.2 Appendix B – Report Transverse tensile tests

Transverse tensile tests composite sheet piles

ASTM D3039 - 17



Project name:	Opwaardering Twentekanalen
Client:	Rijkswaterstaat GPO
Contractor:	Combinatie Van Oord, Hakkers, Beens
Sub contractor:	Witteveen+Bos, TU/e, Dept. of Built Environment

Status:	Final
Revision:	1.0 – 08-03-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0 Prepared by				
	Checked by			
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0		Final Version

Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date tested:	08-03-2023
Test standards:	ASTM D3039 - 17
Material:	E-glass, polyester
Specimen type:	ASTM D3039-17 recommendation
Pre-treatment:	21 °C / 45-50% RV
Machine:	Instron 5985
Pre-load:	0 MPa
Test speed:	2 mm/min
Gage length, standard travel:	50 mm

Table of content

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

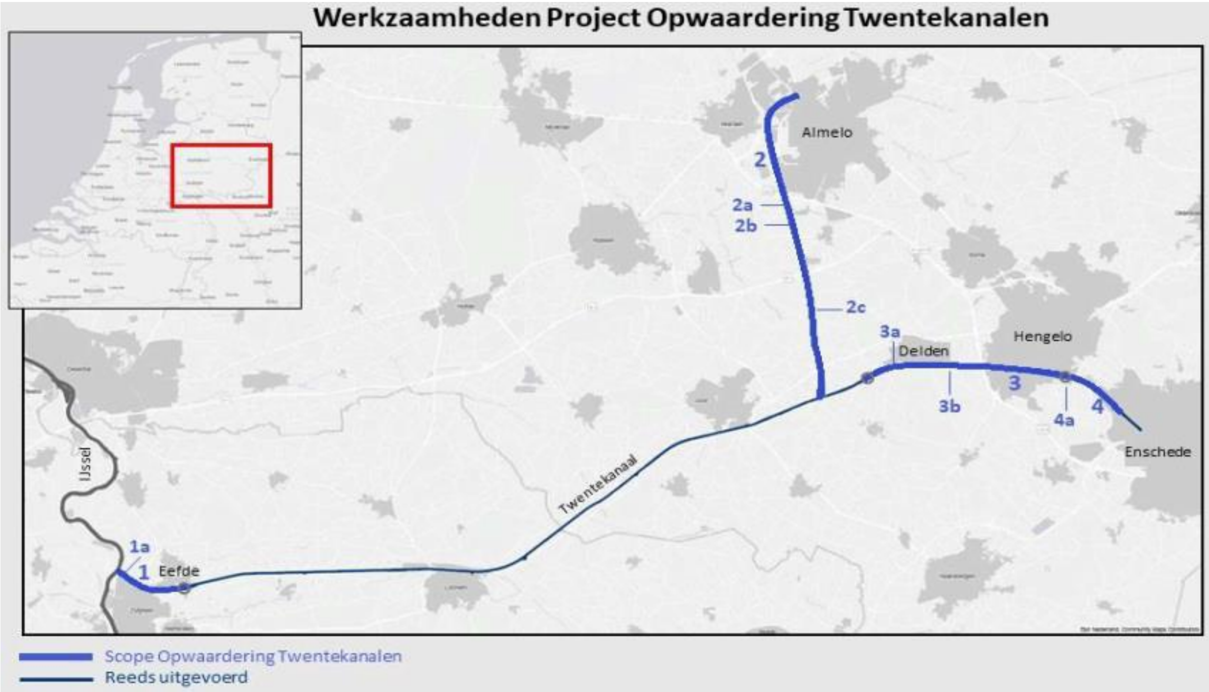


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometre points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **tensile tests in transverse direction** conducted on the composite sheet piles.

2 Test and material

This paper will present the results obtained from the tensile tests conducted on composite sheet piles cut in the transverse direction. The testing methodology adheres to ASTM D3039-2017 standards. It's important to note that the material was subjected to testing both in the direction of the fibres (longitudinal) and perpendicular (transverse) to the fibre direction. However, this report focuses exclusively on the transverse tests.

These sheet piles are constructed from pultruded glass fibre polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in³/ft	703.22	cm³/m
Moment of Inertia	54.01	in⁴/ft	7375.52	cm⁴/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in²	47.94	cm²
Standard Color	Graphite Gray			

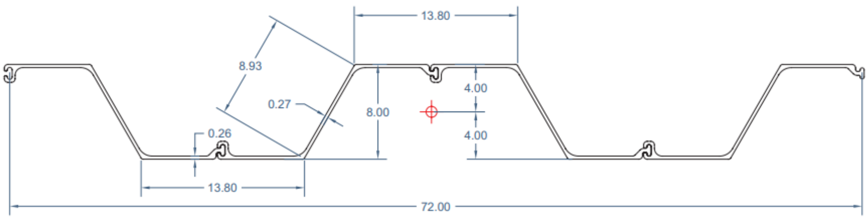
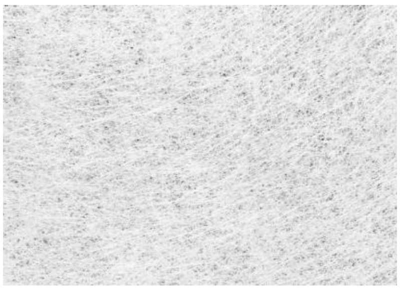


Figure 2-1 Superloc Series 1580

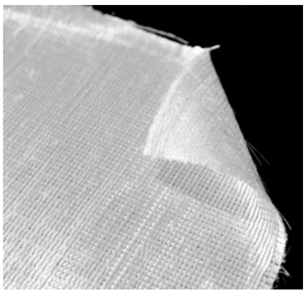
The glass fibre volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibres on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament



0/90 Fabric

0 Direction

Figure 2-2 Visual representation glass fibres used

3 Preparation and equipment used

The specimen dimensions were obtained from ASTM D3039, as outlined in Figure 3-1. Appendix A provides the sawing plan for the samples extracted from the sheet pile elements, with only the samples labelled 'TDxx' being relevant for this test.

The specimen samples were prepared using waterjet cutting at the Equipment and Prototype Centre of the Technical University in Eindhoven. Figures 8-2 and 8-3 in Appendix A illustrate the locations from which the samples were taken on the sheet pile. Following the preparation, no specific consolidation methods were applied, and the samples were stored in the test lab. Additionally, no non-destructive test methods were conducted prior to these tests.

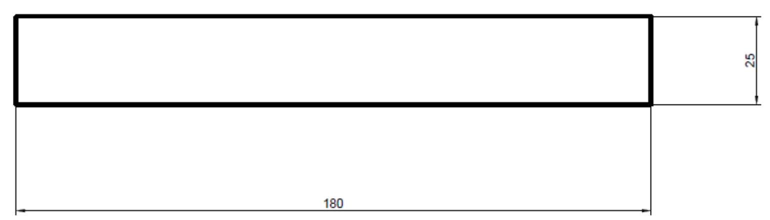
TDxx	

Table 3-1: Sample dimensions

For this test, an Instron 5985 machine manufactured on May 15, 2014, with a capacity of 250kN was utilized. The machine underwent its most recent calibration on February 14, 2022, by NMI Certin. Data was directly collected from the Instron machine using Bluehill Universal computer software to measure the material strain. The data was then exported as CSV files, which were subsequently imported into Excel for data processing.

To measure the material strain, we employed the Instron video extensometer AVE2, which had been calibrated prior to the test. This video extensometer recorded the extension across 2 white dots positioned 50 mm apart on the gauge length of the samples. For determining the average cross-sectional dimensions of the samples, we utilized a digital caliper capable of measuring up to 1/100th of a millimetre. The calibration date for the digital caliper is currently unknown.

The raw data collected for this study included the following types: Time, Force, Displacement, Tensile stress, and Axial strain. To input data into the computer software, we provided the Length, Thickness, and Width parameters. The Width and Thickness were measured at three different points along the gauge length of each sample, and the results are presented in Table 3-2.

Tensile transverse

	Edge	Middle	Edge		Edge	Middle	Edge		
Sample	Width (mm)	Width (mm)	Width (mm)	**Average Width (mm)**	Thickness (mm)	Thickness (mm)	Thickness (mm)	**Average thickness (mm)**	**Average area (mm2)**
TD01	25,11	25,11	25,08	25,10	6,47	6,47	6,44	6,46	162,40
TD02	25,20	25,16	25,16	25,17	6,45	6,48	6,47	6,47	163,12
TD03	24,98	25,04	25,06	25,03	6,41	6,49	6,48	6,46	162,42
TD04	25,30	24,97	25,00	25,09	6,42	6,43	6,48	6,44	161,33
TD05	25,12	25,07	25,01	25,07	6,52	6,46	6,51	6,50	161,93
TD06	24,90	25,05	25,10	25,02	6,48	6,46	6,48	6,47	161,61

Table 3-2: Measured transverse sample dimensions

A total of 6 tensile tests were conducted in the transverse direction of the material. These tests were performed at a testing speed of 2 mm/min. To ensure proper alignment of the samples in the Instron machine, a system depicted in Figure 3-1 was employed. This system includes stops that block the sample, ensuring alignment with the machine's grips.

The samples were securely held in Precision Manual Wedge Grips, model number 2716-030. Importantly, no tabs were utilized during testing, as they were deemed unnecessary since the initial test results were consistent with our expectations.

The standard laboratory conditions were maintained throughout the testing process, with a relative humidity (RH) of 40-50% and a temperature of approximately 21 degrees Celsius. No additional environmental-specific conditions were applied during the tests or the storage of the samples.

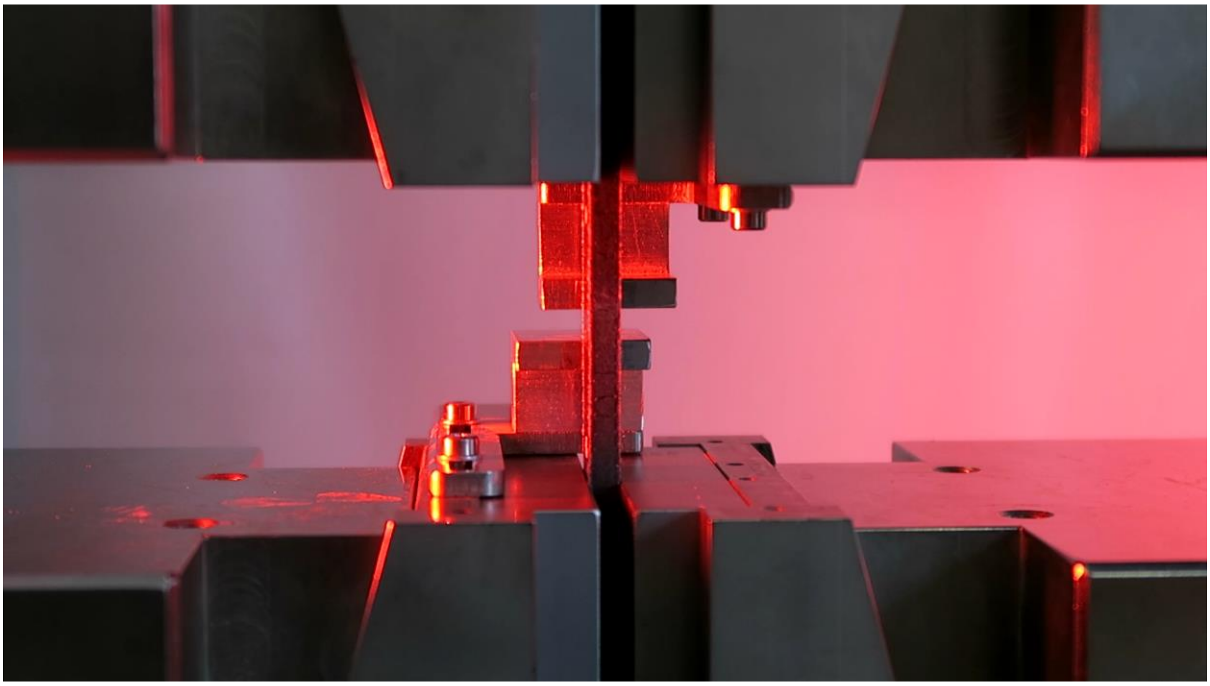


Figure 3-1 Sample alignment in the machine

4 Results

Figure 4-1 displays the force-versus-displacement graphs for the test, and based on this graph, it is evident that TD06 behaves significantly differently from all the other specimens. This unusual behaviour is likely attributed to an error during the preparation of the machine for this test.

To provide more accurate and consistent results, TD06 has been excluded from the analysis, as depicted in Figure 4-2, where the results are presented without TD06.

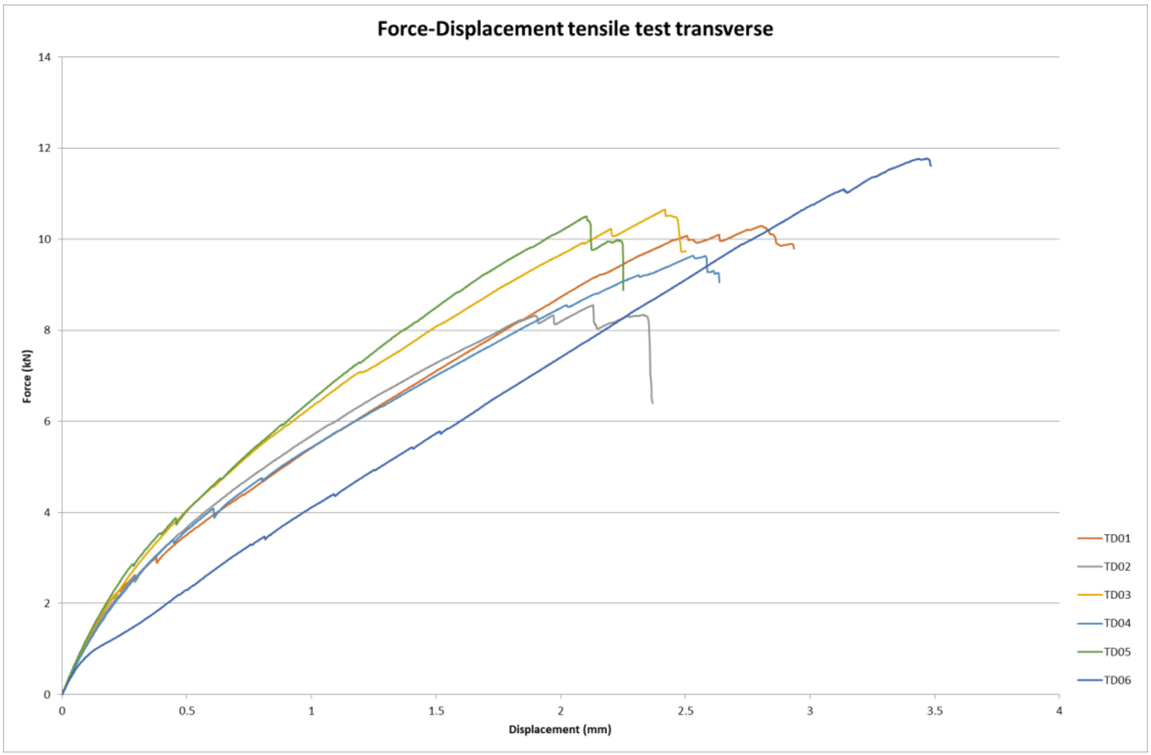


Figure 4-1 Force displacement of the tensile test in transverse direction

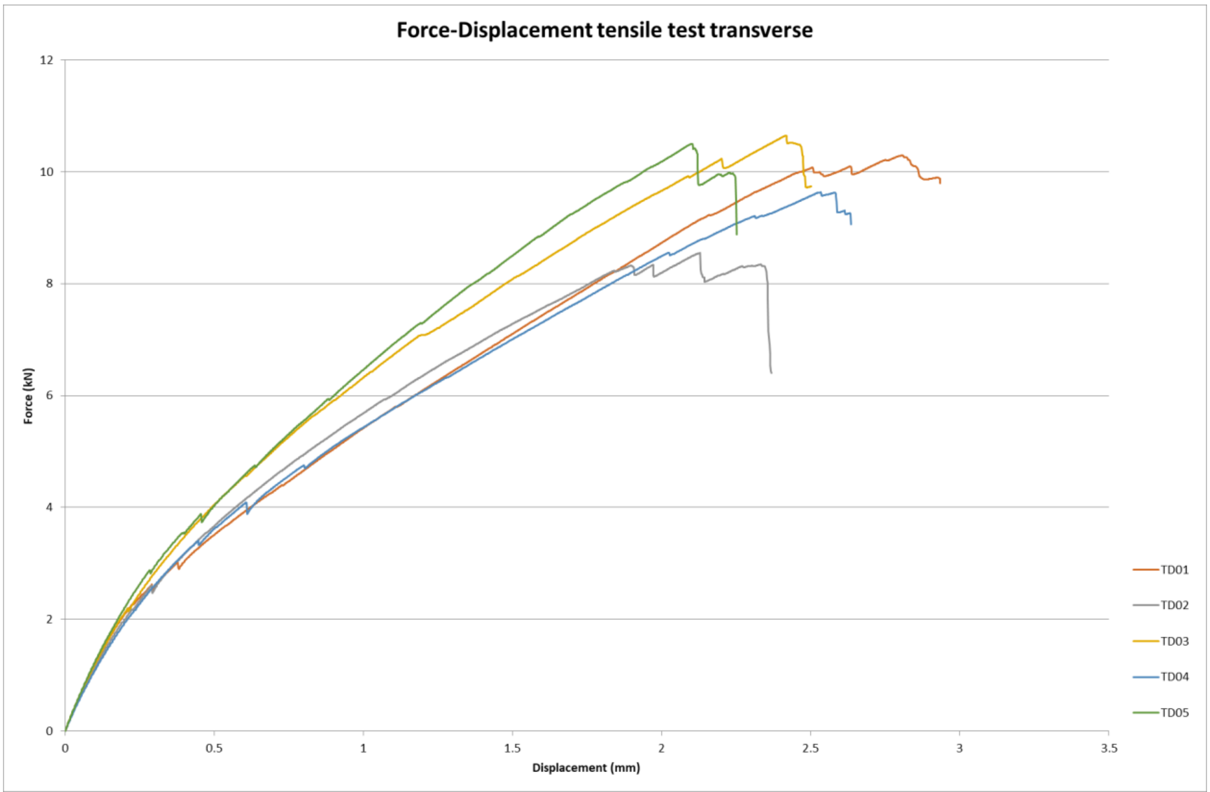
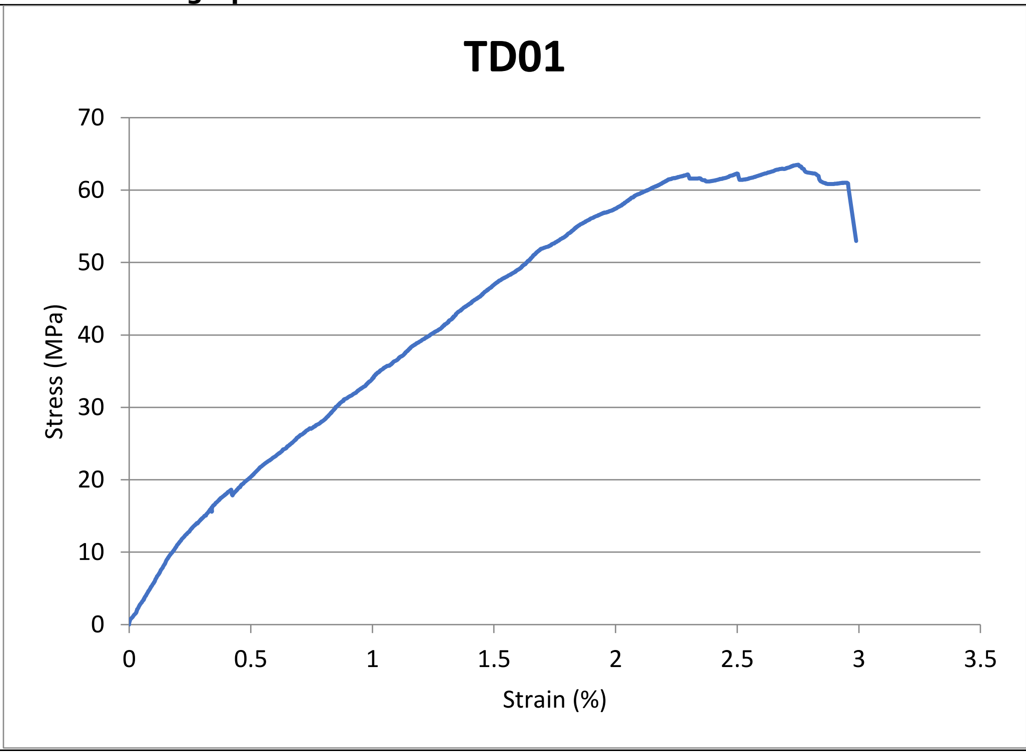
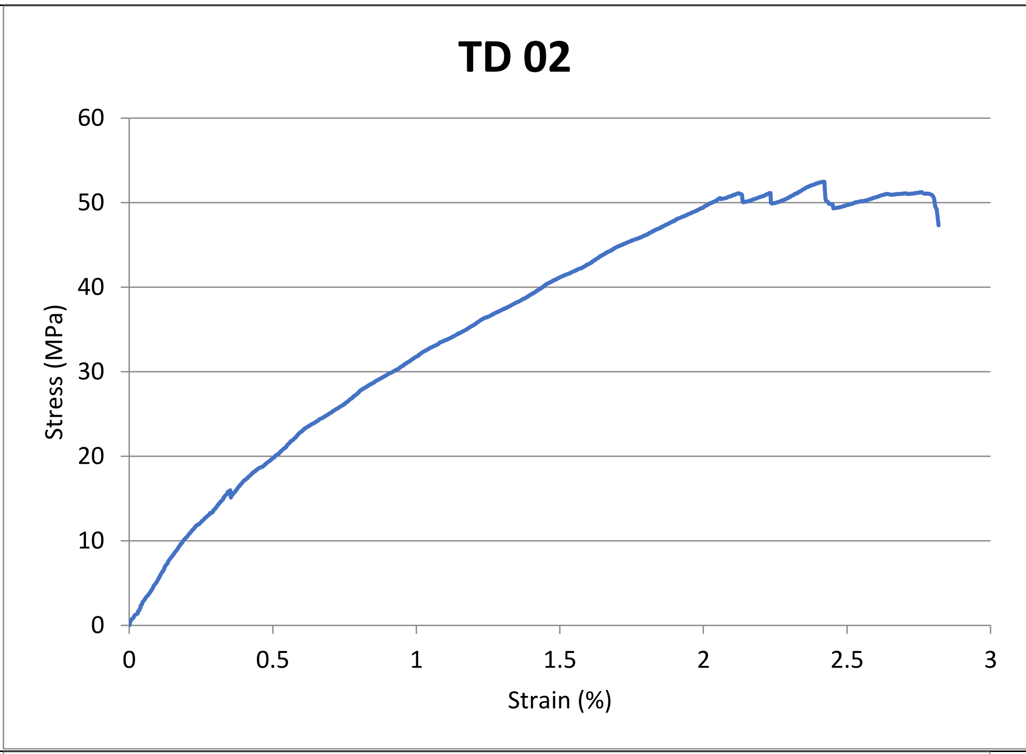
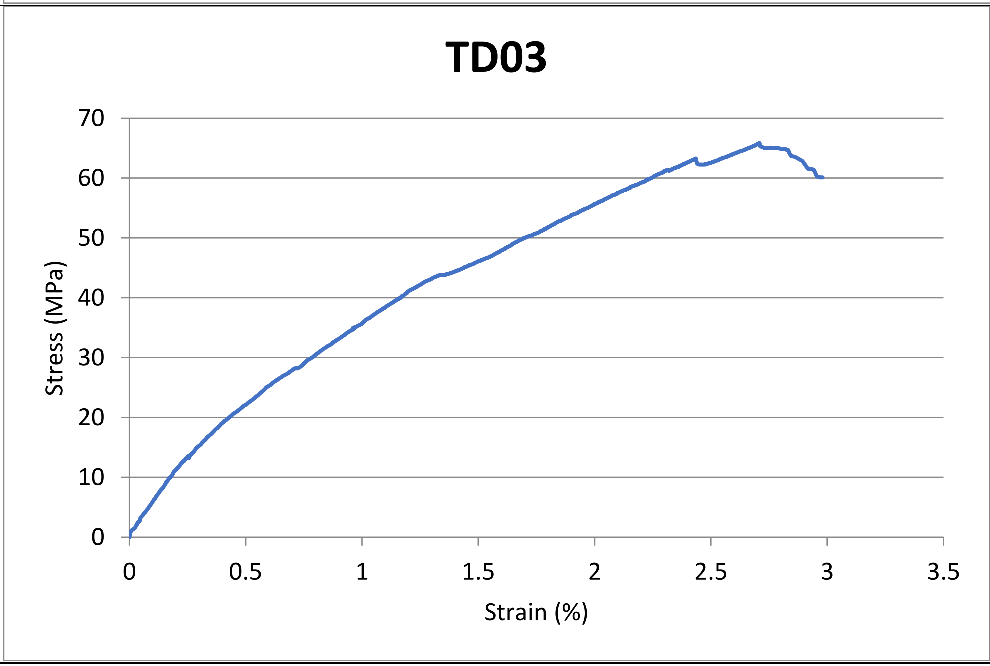


Figure 4-2 Force displacement of the tensile test in transverse direction - corrected

Test:	Stress-strain graph
TD01	

TD02	TD 02 60 50 40 30 20 10 0 Stress (MPa) 0 0.5 1 1.5 2 2.5 3 Strain (%)
TD03	TD03 70 60 50 40 30 20 10 0 Stress (MPa) 0 0.5 1 1.5 2 2.5 3 3.5 Strain (%)

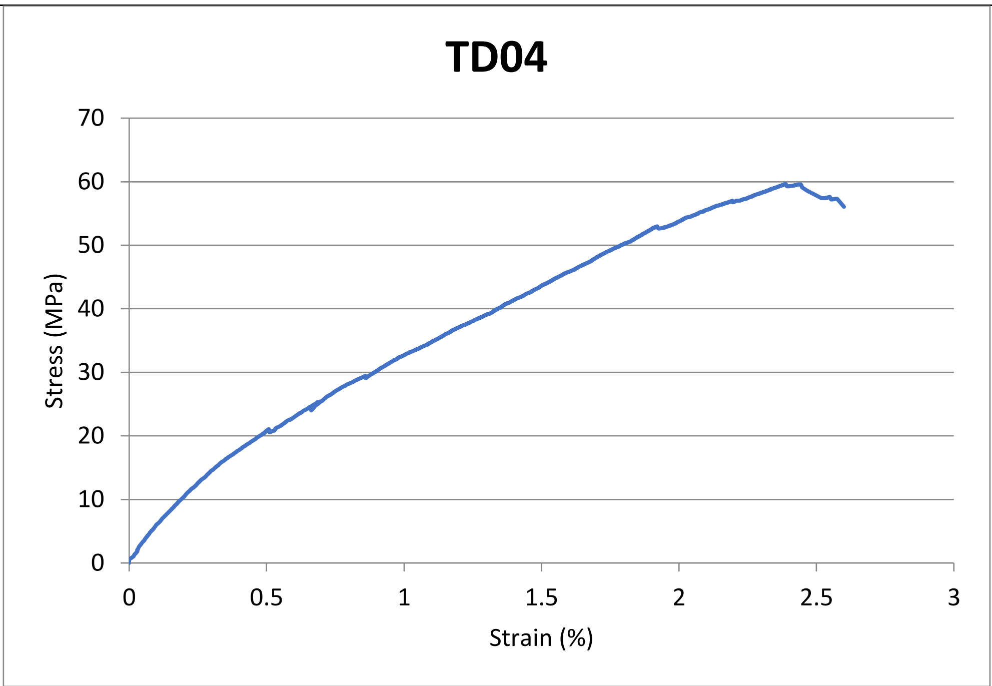
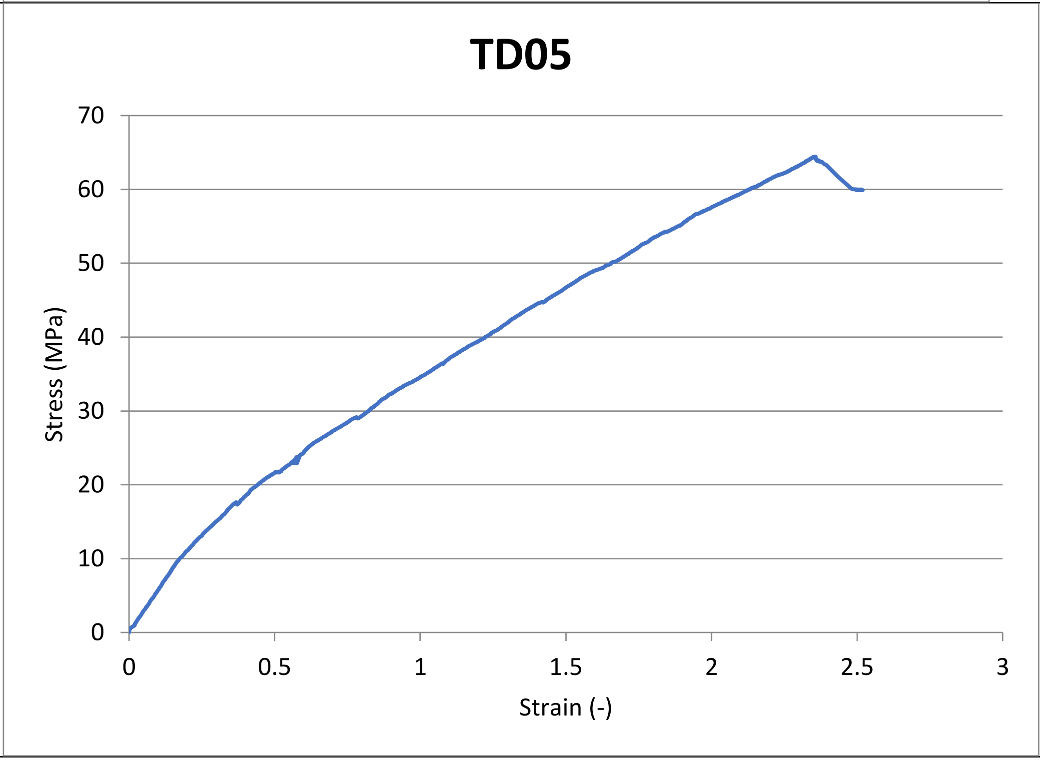
TD04	
TD05	

Table 4-1: Stress/Strain graphs transverse direction

5 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value

n = number of tests

V_x = Which is the coefficient of variation $V_x = S_x/m_x$

S_x = Standard deviation

m_x = average value

k_n = Static factor which can be calculated with $k_n = K^* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.

K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 5-1: k_n values

6 Transverse tensile strength

6.1 Ultimate tensile strength and stress

Table 6-1 provides the ultimate tensile strength and stress values for each specimen tested in the transverse direction of the material. It's noted that the results show a satisfactory distribution.

Individual Strength and Stress

Sample	Max Force (kN)	Deviation (kN)	Max Stress (MPa)	Deviation (MPa)
TD01	10.30	0.372	63.55	2.34
TD02	8.55	-1.378	52.53	-8.68
TD03	10.65	0.722	65.85	4.64
TD04	9.64	-0.288	59.66	-1.54
TD05	10.50	0.572	64.46	3.25
Average strenght (kN)	9.93	Average strenght (MPa)	61.21	
Standard deviation (kN)	0.861	Standard deviation (MPa)	5.369	
Coefficient of variation (%)	9%	Coefficient of variation (%)	9%	
Coefficient of variation	0.0868	Coefficient of variation	0.0877	
K	1.645	K	1.645	
kn	1.80	kn	1.80	
n	5	n	5	
Rk (kN)	8.377	Rk (MPa)	51.54	

Table 6-1: Individual strength and stress transverse direction

6.2 Strain at failure

Table 6-2 displays the strains at failure for the tensile tests conducted in the transverse direction. The data indicates that the strains at failure of the samples follow a normal distribution.

Individual Strain at failure

Sample	Strain (%)	Deviation (%)
TD01	2.75	0.224
TD02	2.42	-0.106
TD03	2.71	0.184
TD04	2.39	-0.136
TD05	2.36	-0.166
Average (%)	2.53	
Standard deviation (%)	0.188	
Coefficient of variation (%)	7%	
Coefficient of variation	0.0744	
K	1.645	
kn	1.80	
n	5	
Rk (%)	2.19	

Table 6-2: Individual Strain at failure of the samples

6.3 E-modulus

Table 6-3 contains the data utilized for calculating the E-Modulus in the transverse direction of the material.

E-Modulus								
	Strain			Stress			E-Modulus	Deviation
Sample	0.1%	0.3%	delta (-)	0.1%	0.3%	delta (MPa)	(MPa)	(Mpa)
TD01	0.0009958	0.0029961	0.0020003	5.6616	14.6501	8.9885	4494	17
TD02	0.0009884	0.0029962	0.0020078	5.4169	13.8873	8.4704	4219	-257
TD03	0.0009937	0.0029952	0.0020015	5.714	15.2033	9.4893	4741	265
TD04	0.0010055	0.0029912	0.0019857	6.0683	14.526	8.4577	4259	-217
TD05	0.0010027	0.0029950	0.0019923	5.7292	15.0291	9.2999	4668	192
						Average (MPa)	4476	
						Standard deviation (MPa)	234.8	
						Coefficient of variation (%)	5%	
						Coefficient of variation	0.05246	
						K	1.645	
						kn	1.8	
						n	5	
						Rk (Mpa)	4053	

Table 6-3: E-Modulus transverse

6.4 Failure mode

For the samples cut in the transverse direction of the material, it's worth noting that all specimens exhibited a consistent failure mechanism. The specimens experienced an angled failure across the width of the sample, primarily occurring at the gage area and at various locations within the sample. According to the ASTDM D3039 classification, this failure mechanism corresponds to AGV. Visual documentation of all the failed specimens can be found in Figure 6-1, while Figures 6-2 and 6-3 provide close-up pictures of the failure for further detail.

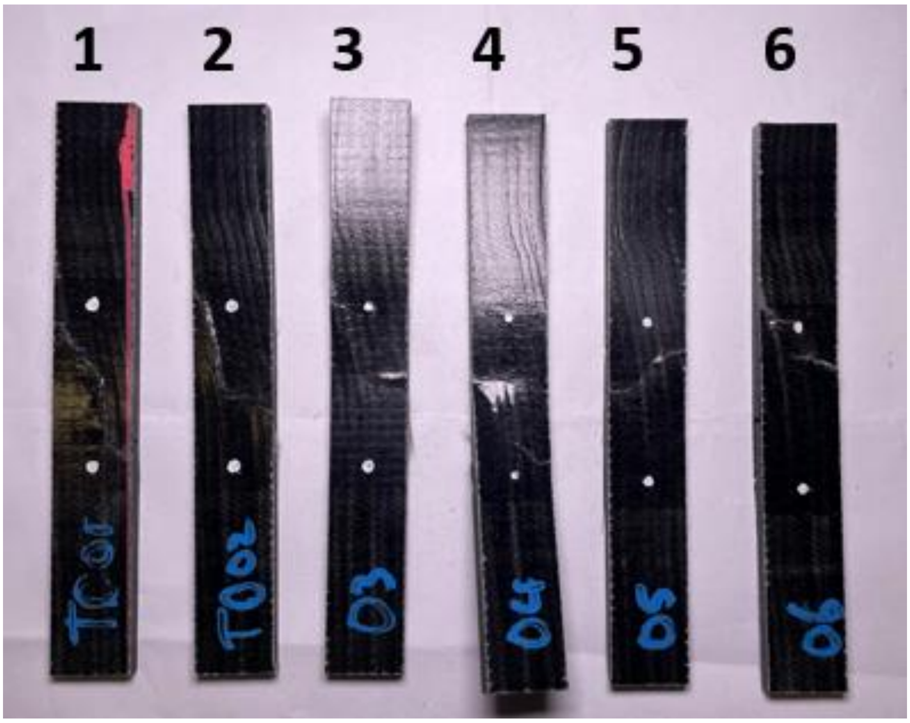


Figure 6-1 Failure mechanism transverse (1)


Figure 6-2 Failure mechanism transverse (2)


Figure 6-3 Failure mechanism transverse (3)

7 Summary

In summary, the results obtained from the transverse tensile tests yield the following findings, as presented in Table 7-1.

Results tension in transverse direction	
Characteristic Strength	8.4 kN
Characteristic Stress	51.54 MPa
Characteristic Strain at failure	2.19 %
Characteristic E-Modulus	4053 MPa

table 7-1 Material properties according to tensile test

8 Appendix

8.1 Appendix A – Sample numbering

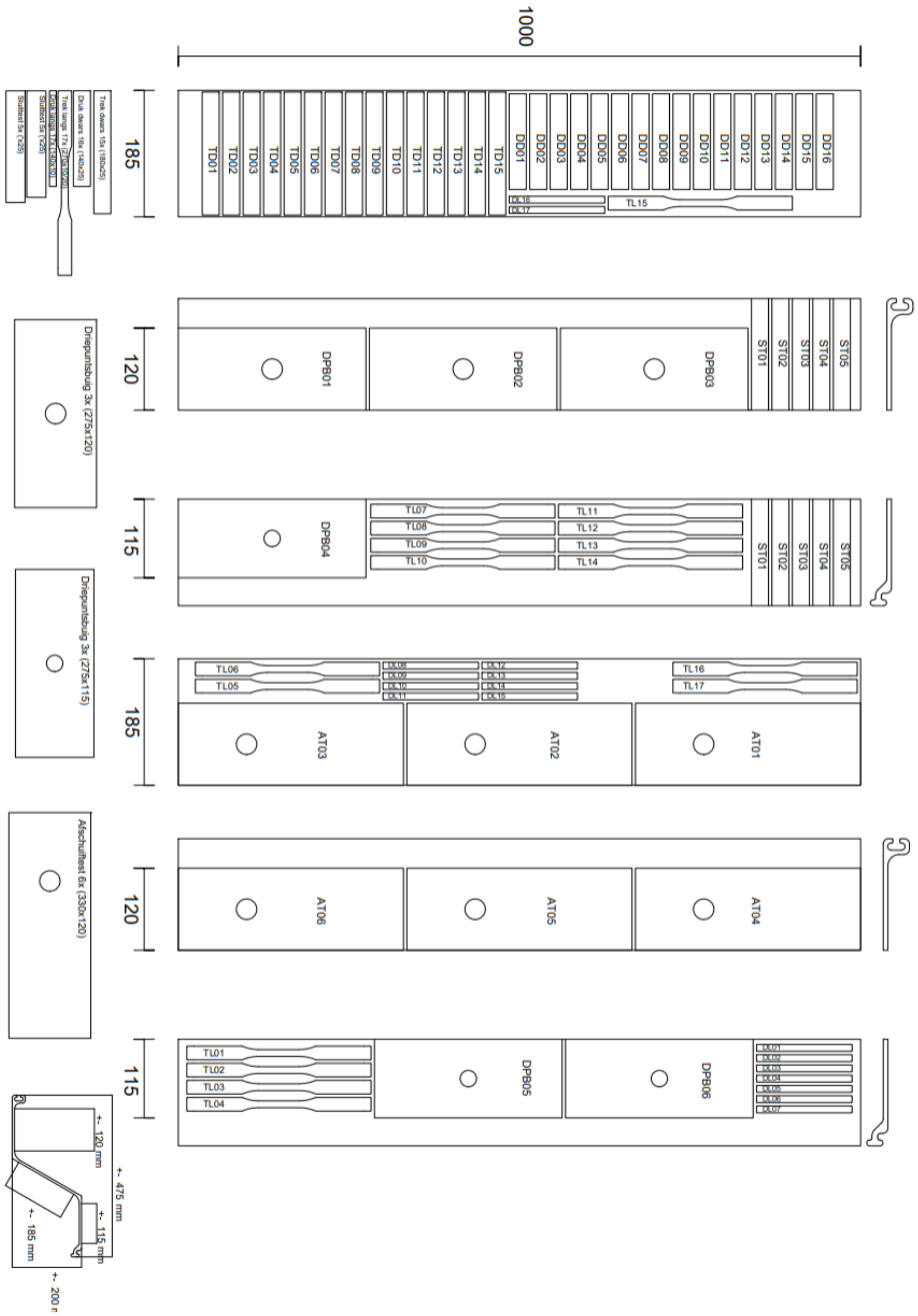


Figure 8-1 Saw plan all samples

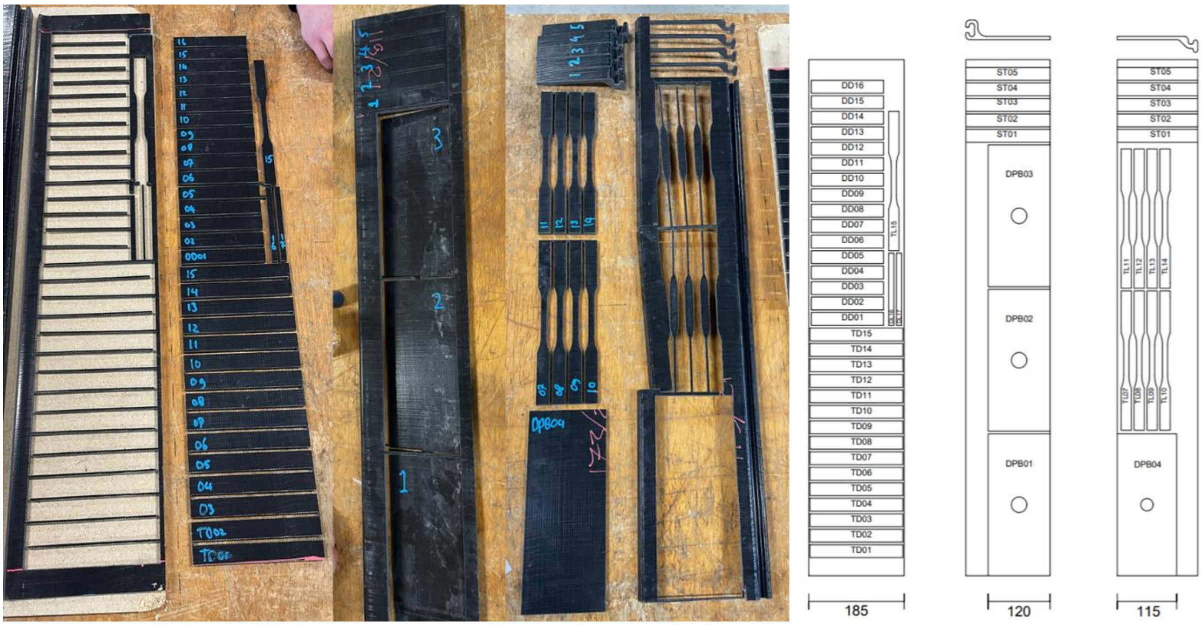


Figure 8-2 Samples retrieved from sheet

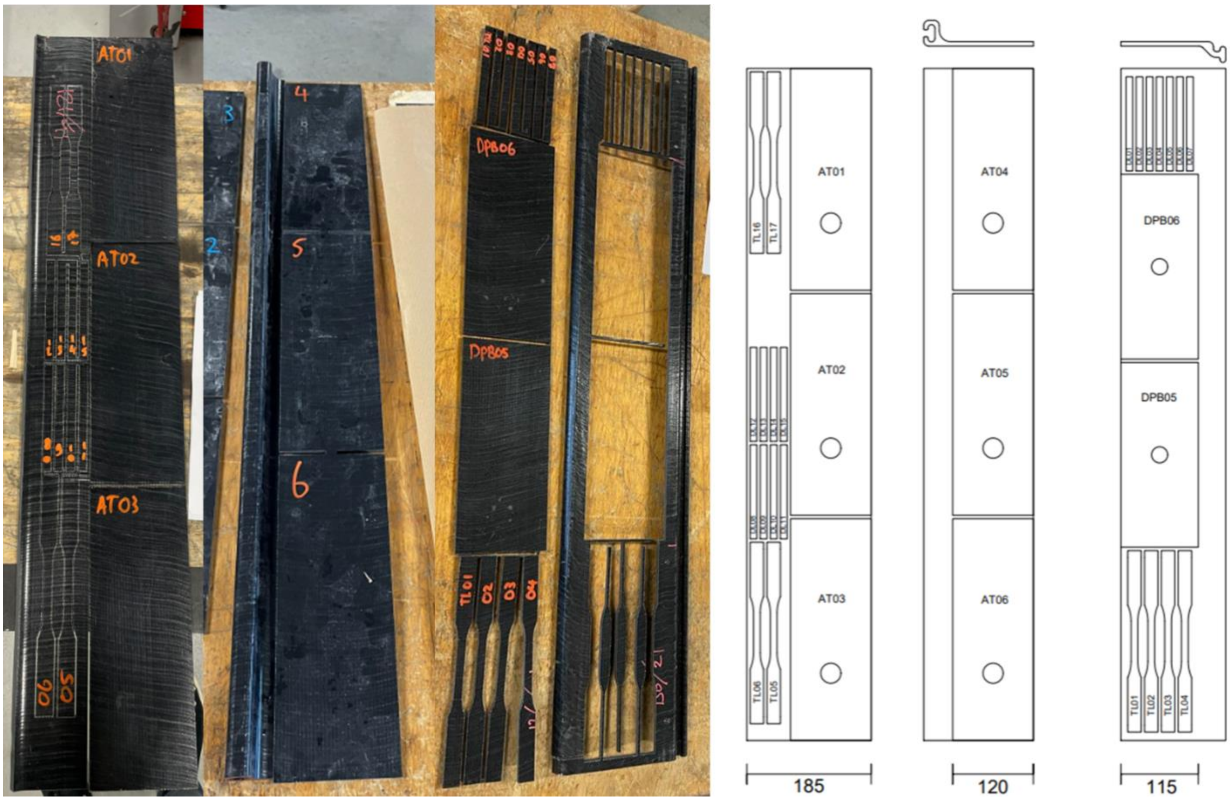
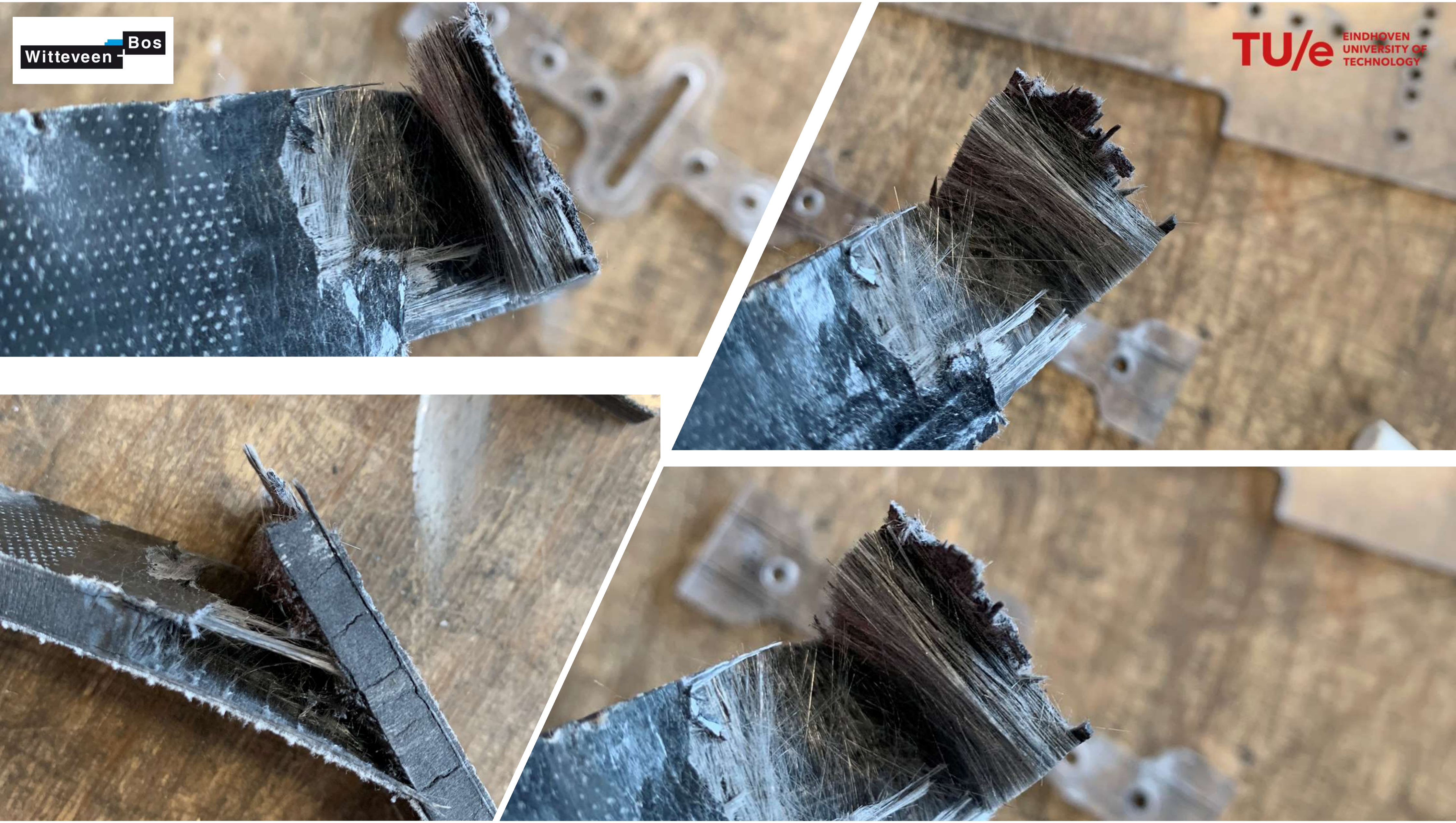
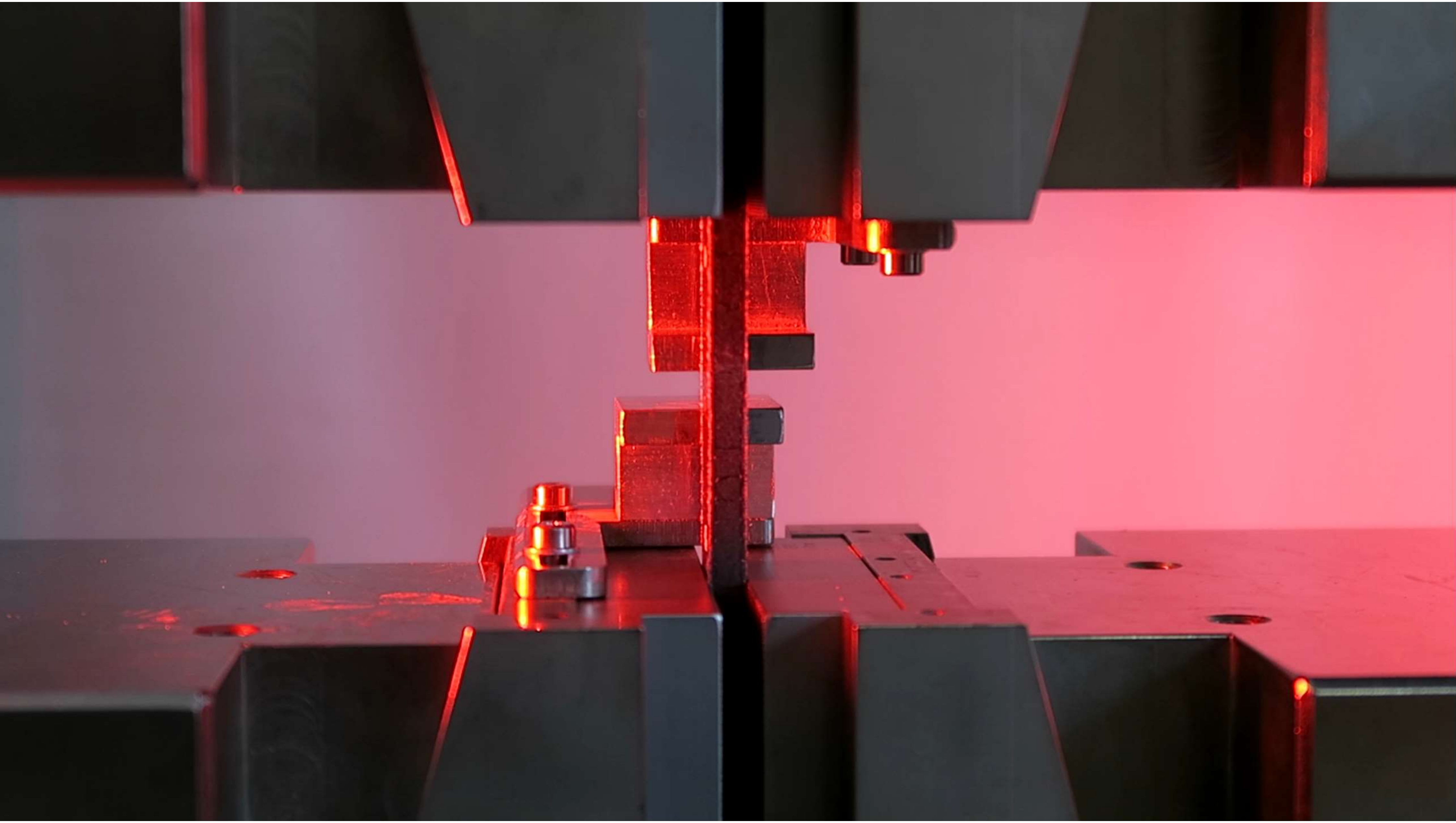


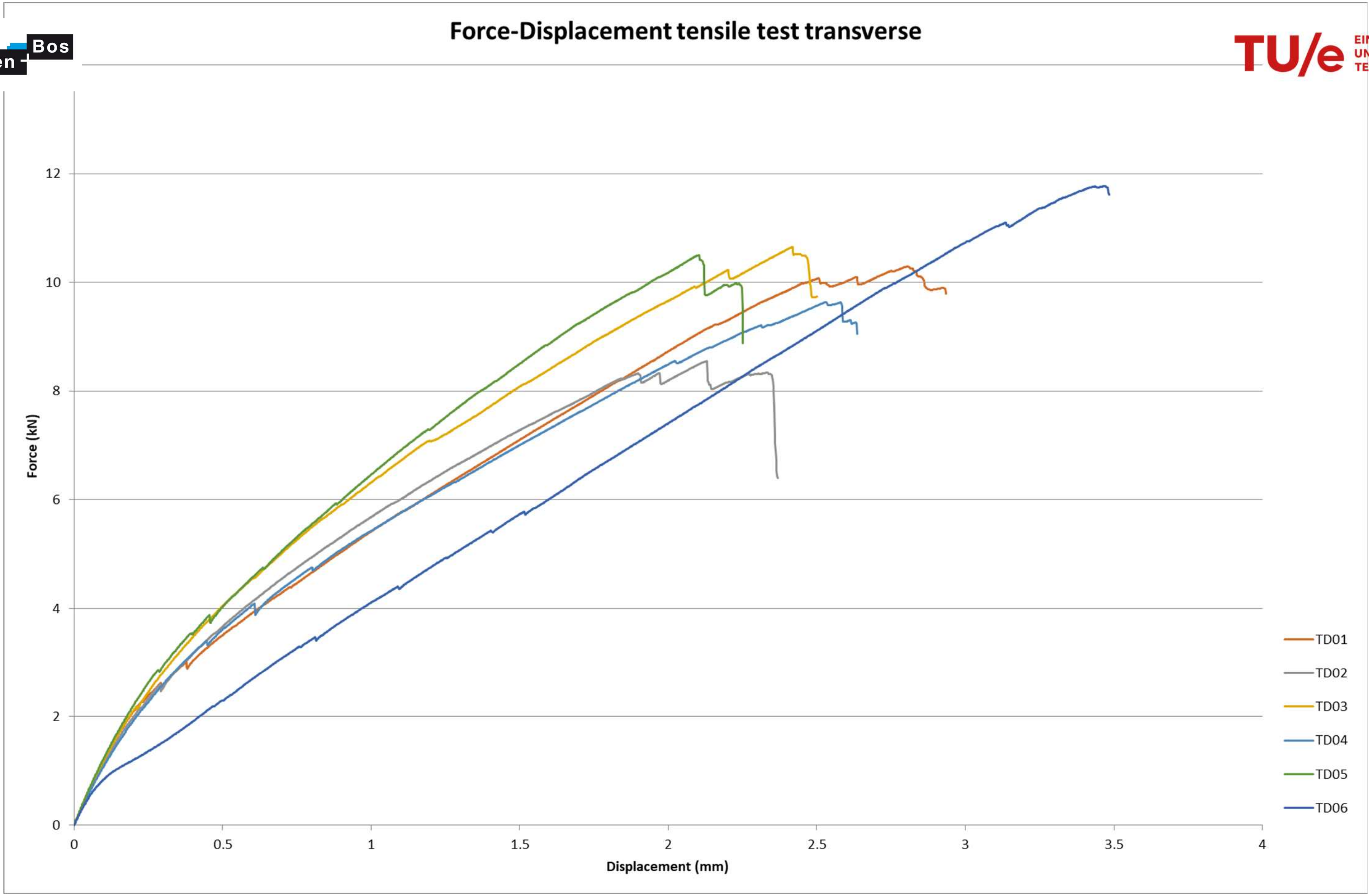
Figure 8-3 Samples retrieved from sheet

8.2 Appendix B – Presentation results and test

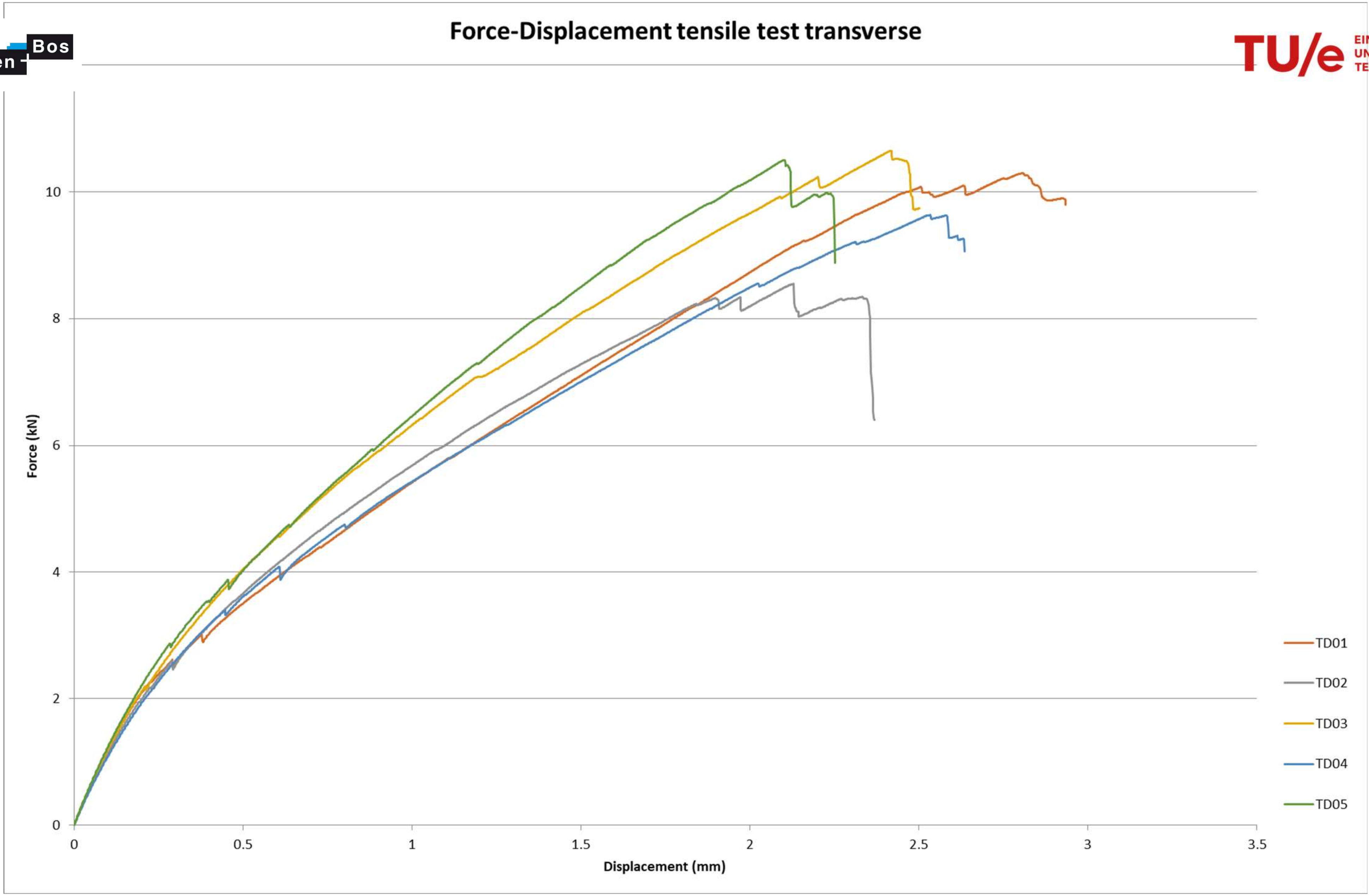
Transverse tensile tests composite sheet piles


Witteveen+Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY





Force-Displacement tensile test transverse
Force (kN)
Displacement (mm)
0
2
4
6
8
10
12
0
0.5
1
1.5
2
2.5
3
3.5
4
TD01
TD02
TD03
TD04
TD05
TD06



Force-Displacement tensile test transverse
Force (kN)
0
2
4
6
8
10
Displacement (mm)
0
0.5
1
1.5
2
2.5
3
3.5
TD01
TD02
TD03
TD04
TD05

5.3 Appendix C – Report Longitudinal compressive tests

Longitudinal compressive tests composite sheet piles

ASTM D3410M - 03

Projectnaam: Opwaardering Twentekanalen
Opdrachtgever: Rijkswaterstaat GPO
Opdrachtnemer: Combinatie Van Oord, Hakkers, Beens
Onderaannemer: Witteveen+Bos, TU/e, Dept. of Built Environment

Status: Definitief
Revisie: 1.0 – 22-03-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0	Prepared by			
	Checked by			
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0		Final Version

Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date tested:	22-03-2023
Test standards:	ASTM D3410M - 03
Material:	E-glass, polyester
Specimen type:	ASTM D3410M - 03
Pre-treatment:	21 °C / 45-50% RV
Machine:	Instron 5985
Pre-load:	0 MPa
Test speed:	1.3 mm/min
Gage length, standard travel:	10 mm

Inhoudsopgave

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

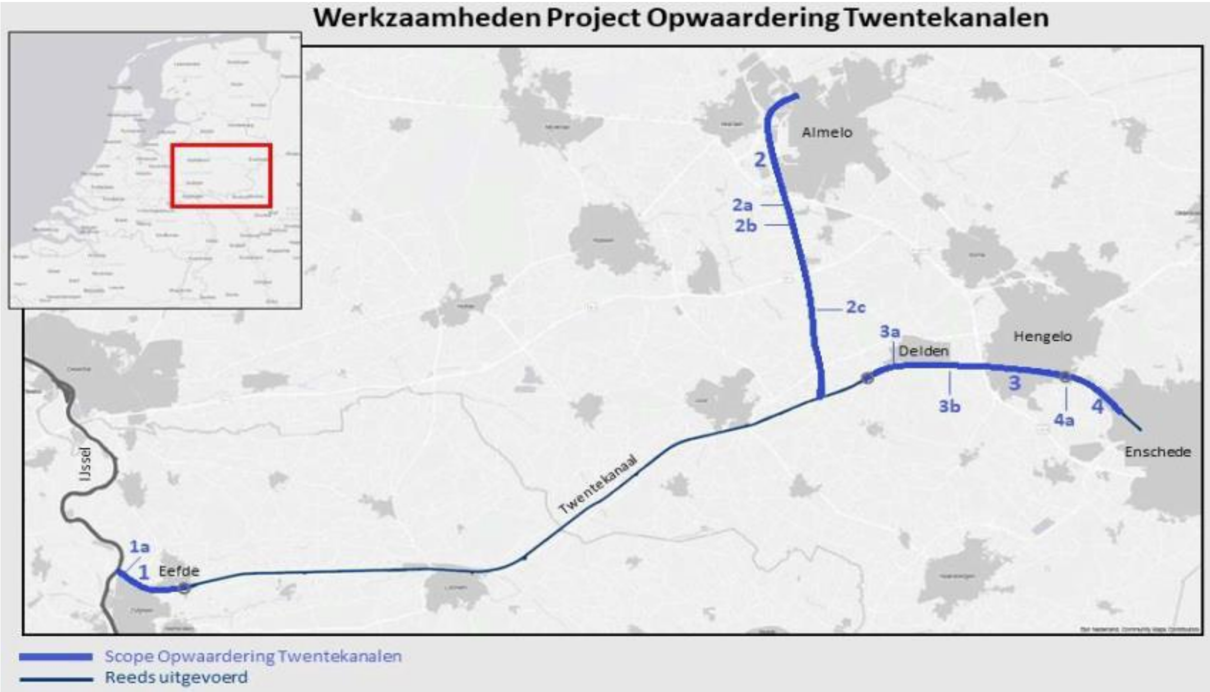


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometer points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **compression tests in longitudinal direction** conducted on the composite sheet piles.

2 Test and material

This paper will present the results obtained from the compression tests conducted on composite sheet piles. The testing procedure adheres to ASTM D3410M_2003 standards, including the dimensions prescribed by ASTM D3410M_2003. The material is tested along the fiber direction, which is the longitudinal direction.

These sheet piles are constructed from pultruded glass fiber polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in³/ft	703.22	cm³/m
Moment of Inertia	54.01	in⁴/ft	7375.52	cm⁴/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in²	47.94	cm²
Standard Color	Graphite Gray			

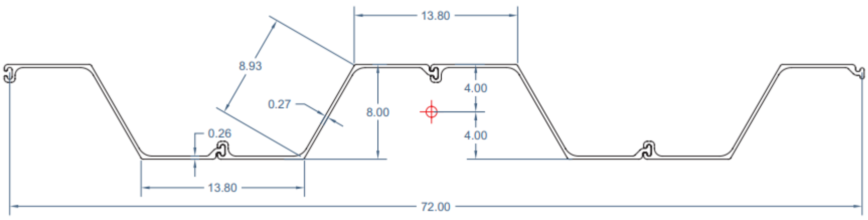
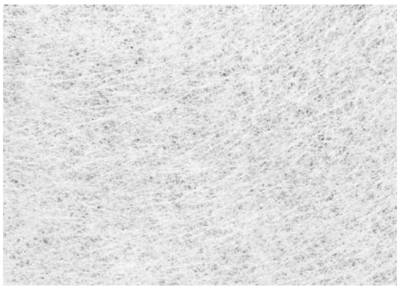


Figure 2-1 Superloc Series 1580

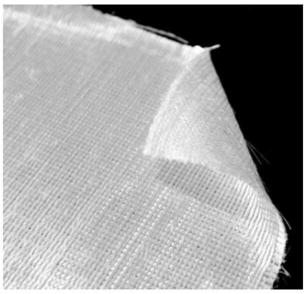
The glass fiber volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibers on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament



0/90 Fabric

0 Direction

Figure 2-2 Visual representation glass fibers used

3 Preparation and equipment used

The specimen dimensions were obtained from ASTM D3410M - 03, as shown in Table 3-1. Appendix A contains the sawing plan for the samples, which were extracted from the sheet pile elements. Only the samples labeled 'DDxx' are relevant for this test. These specimen samples were prepared using waterjet cutting at the Equipment and Prototype Center of the Technical University in Eindhoven. Figures 8-1, 8-2, and 8-3 in Appendix A depict the locations from which the samples were extracted from the sheet pile. No specific consolidation methods were applied afterward, and the samples were stored in the test lab. No nondestructive test methods were employed prior to this test.

DLxx

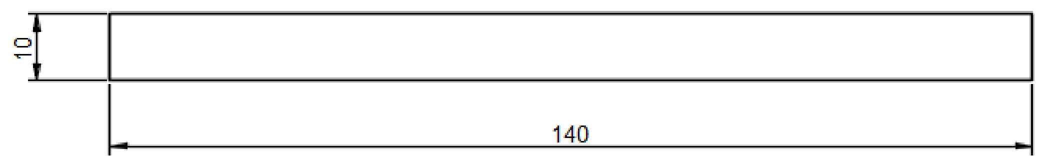


Table 3-1: Sample dimensions

For this test, an Instron 5985 machine manufactured on May 15, 2014, with a capacity of 250kN was utilized. The machine underwent its most recent calibration on February 14, 2022, by NMI Certin. Data was directly collected from the Instron machine using Bluehill Universal computer software to measure the material strain. The data was then exported as CSV files, which were subsequently imported into Excel for data processing.

The raw data included Time, Force, Displacement, and Compressive Stress. The input data for the computer software consisted of Length, Thickness, and Width. Width and thickness were measured at three points for each sample, and the results are presented in Table 3-2.

Compression longitudinal

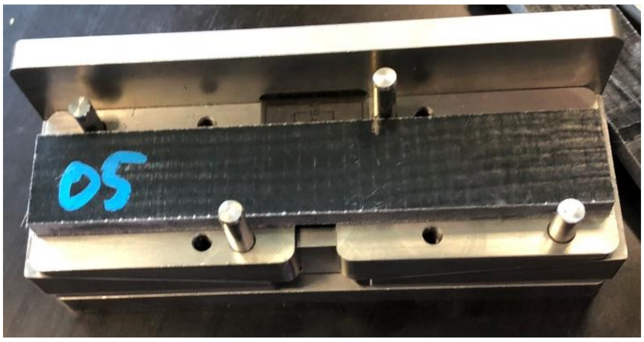
	Edge	Middle	Edge		Edge	Middle	Edge		
Sample	Width (mm)	Width (mm)	Width (mm)	**Average width (mm)**	Thickness (mm)	Thickness (mm)	Thickness	**Average thickness**	**Average area (mm2)**
DL02	9.85	9.92	10.07	**9.95**	6.81	6.81	6.79	**6.80**	**67.74**
DL03	10.39	10.31	10.19	**10.30**	6.78	6.82	6.81	**6.80**	**70.22**
DL04	9.80	9.93	10.09	**9.94**	6.74	6.77	6.79	**6.77**	**67.29**
DL05	10.29	10.27	10.22	**10.26**	6.81	6.75	6.76	**6.77**	**69.26**
DL06	9.95	9.99	10.09	**10.01**	6.72	6.74	6.78	**6.75**	**67.47**
DL07	10.12	10.15	10.15	**10.14**	6.74	6.74	6.73	**6.74**	**68.34**

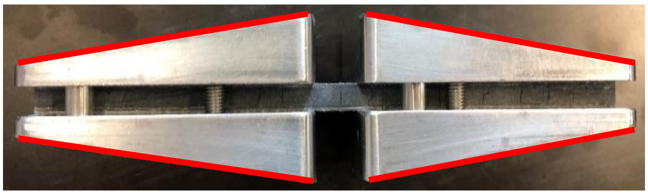
Table 3-2: Measured lognitudinal sample dimensions

A total of 6 compressive tests were conducted in the longitudional direction of the material. A testing speed of 1.3 mm/min was employed. For testing, we utilized a Sophia gripper ASTM D 3410 in addition to the Precision Manual Wedge Grips model number 2716-030 from the Instron machine.

Initially, the samples were placed in the Sophia gripper, as shown in Figures 3-1 and 3-2. Subsequently, the Sophia gripper was aligned within the Instron machine using the system illustrated in Figure 3-3. Figure 3-3 also displays two Linear Variable Differential Transformers (LVDTs) indicated by yellow ovals on both sides of the Instron test alignment. These LVDTs are from the Instron 2601 series and were used to measure the displacement of the specimen.

No tabs were used during testing, as they were deemed unnecessary since the failure results aligned with our initial expectations for the initial tests. The laboratory conditions maintained a relative humidity (RH) of 40-45% and a temperature of approximately 21 degrees Celsius. No other specific environmental conditions were applied during the tests or the storage of the samples.





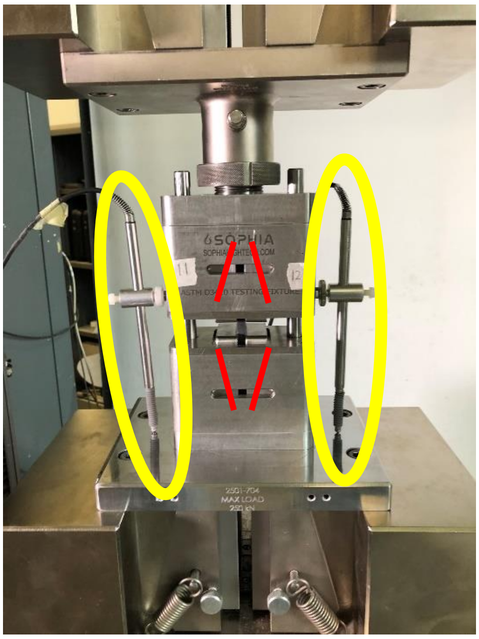


Figure 3-1 Sample placed in Sophia gripper (top left)
Figure 3-2 Sample placed in Sophia gripper (bottom left)
Figure 3-3 Sophia gripper aligned in the Instron (right)

4 Results

Figure 4-1 presents the relationship between force and displacement in the compressive test conducted in the longitudinal direction. The results indicate that the maximum force before failure in the longitudinal direction ranges between 35.0kN and 37.8kN. Table 4-1 provides the force/displacement graphs for each sample in the longitudinal direction.

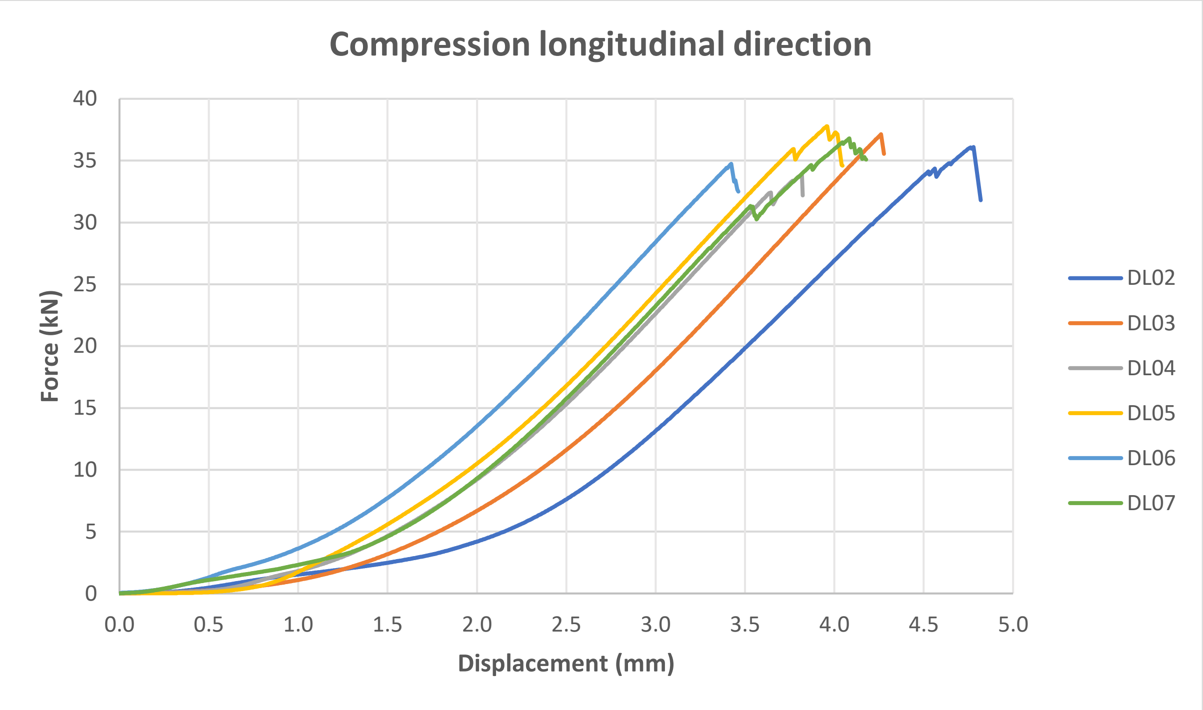
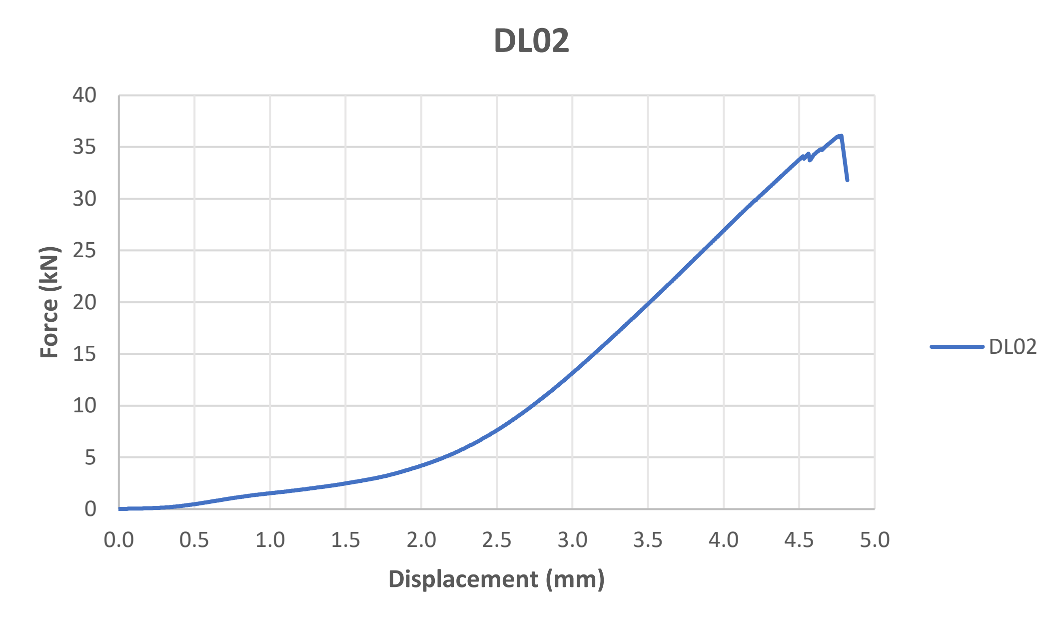
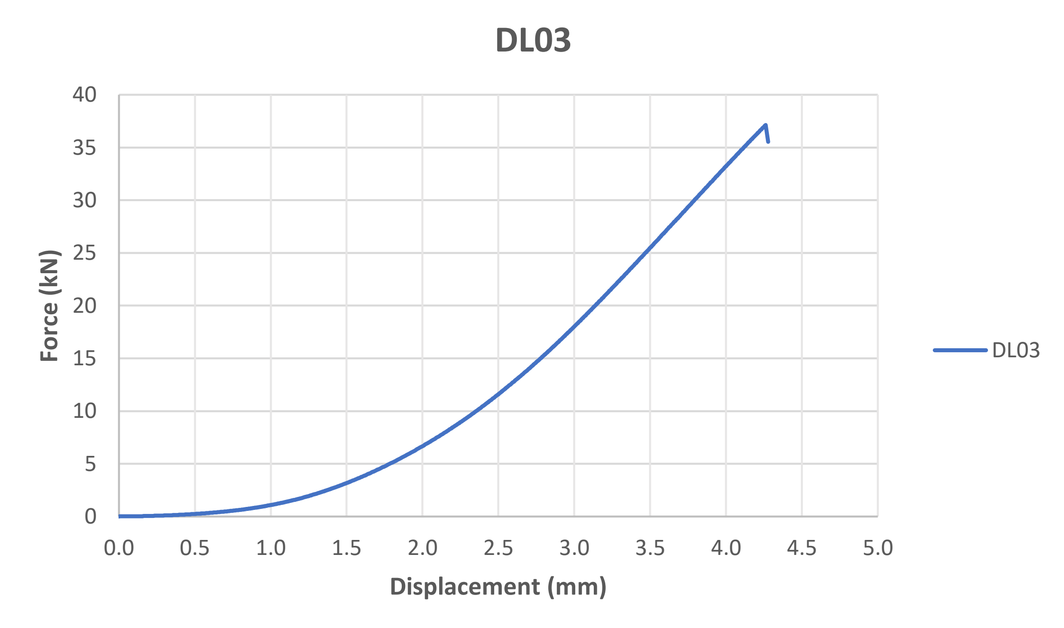
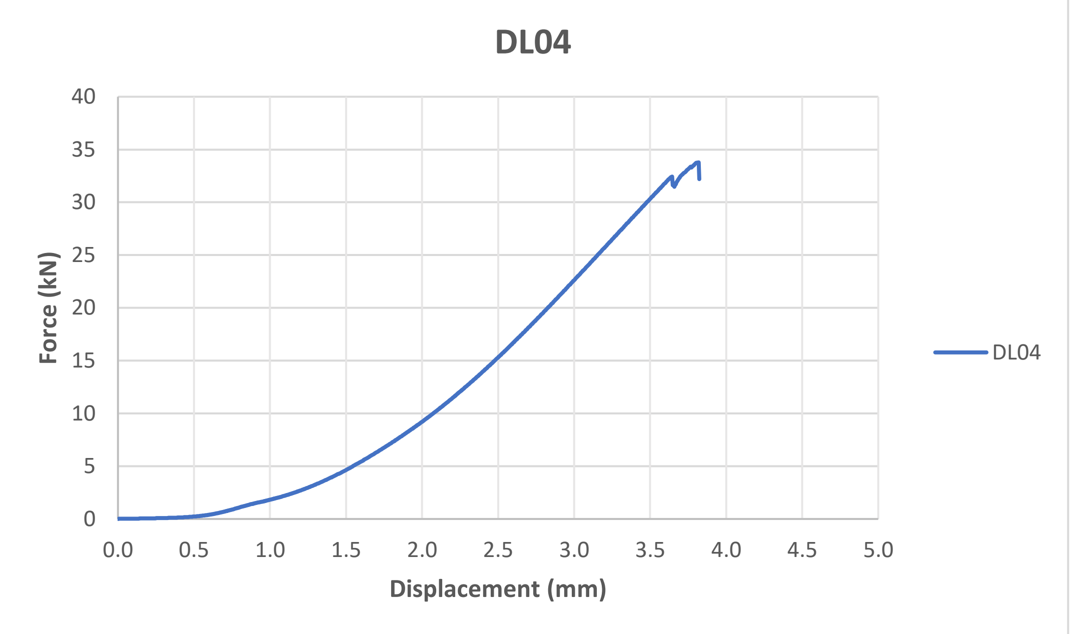
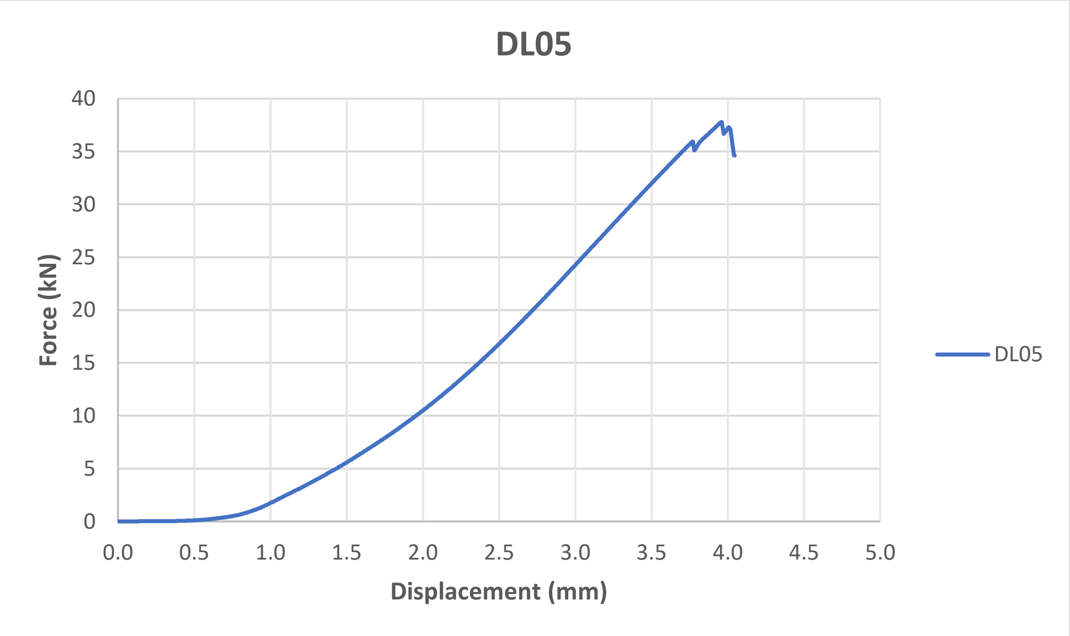


Figure 4-1 Force-displacement of the compressive test in longitudinal direction

Test:	Force/Displacement graphs
DL 02	
DL 03	

DL 04	DL04 Force (kN) Displacement (mm) DL04 0 5 10 15 20 25 30 35 40 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
DL 05	DL05 Force (kN) Displacement (mm) DL05 0 5 10 15 20 25 30 35 40 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

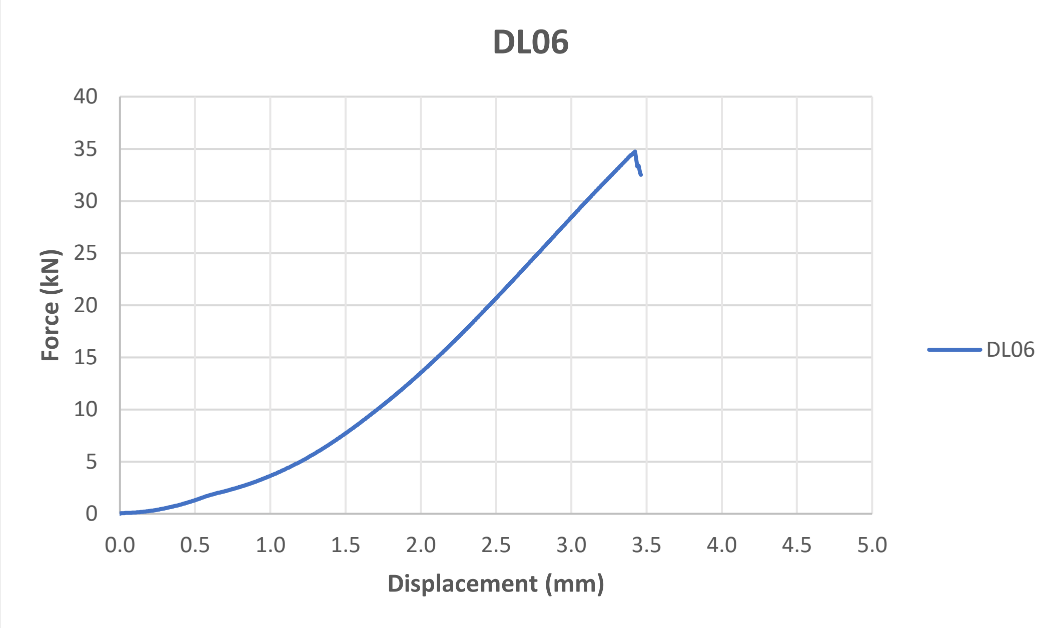
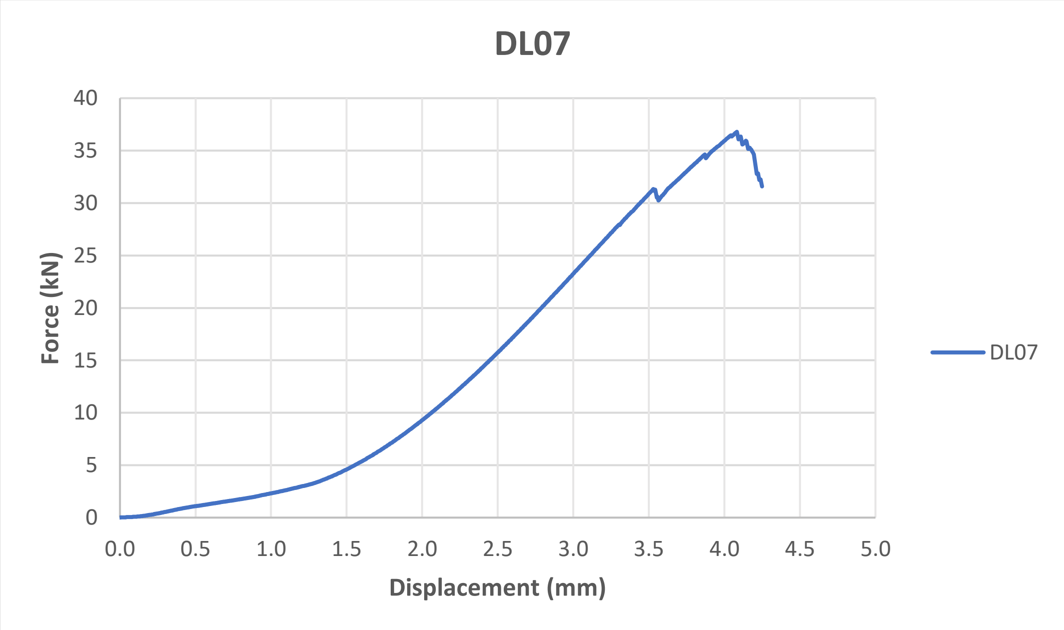
DL 06	
DL 07	

Table 4-1: Force/Displacement graphs longitudinal direction

5 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value

n = number of tests

V_x = Which is the coefficient of variation $V_x = S_x/m_x$

S_x = Standard deviation

m_x = average value

k_n = Static factor which can be calculated with $k_n = K* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.

K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 5-1: k_n values

6 Longitudinal compressive strength

6.1 Ultimate compressive strength and stress

Table 6-1 includes the ultimate compressive strength and stress values for each specimen tested in the longitudinal direction of the material.

Individual Strength and Stress

Sample	Max Force (kN)	Deviation (kN)	Max Stress (MPa)	Devation (MPa)
DL02	36,10	-0,162	533,5	3,50
DL03	37,66	1,395	537,6	7,60
DL04	34,49	-1,772	512,5	-17,52
DL05	37,78	1,521	543,9	13,90
DL06	34,74	-1,520	514,2	-15,86
DL07	36,80	0,538	538,4	8,40
Average (kN)	36,26	**Average (MPa)**	530,04	
Standard deviation (kN)	1,29	**Standard deviation (MPa)**	12,20	
Coefficient of variation (%)	3,56	**Coefficient of variation (%)**	2,30	
K	1,645	**K**	1,645	
kn	1,777	**kn**	1,777	
n	6	**n**	6	
Rk(kN)	33,96	**Rk(MPa)**	508,37	

Table 6-1: Individual strength and stress longitudinal direction

6.2 E-Modulus and Strain at failure

The E-Modulus and Strain at failure must be determined following ASTM D3410M. In these tests, a Sophia gripper, as previously described in this document, was utilized for the compressive tests. This gripper is intended for specimens with precise thicknesses ranging from 1 to 10 mm. However, the composite sheet piles do not possess an exact thickness (for instance, not precisely 4 mm). As a result, the wedges of the Sophia gripper did not fit entirely within the gripper (see figure 6-1), leading to wedges displacement.

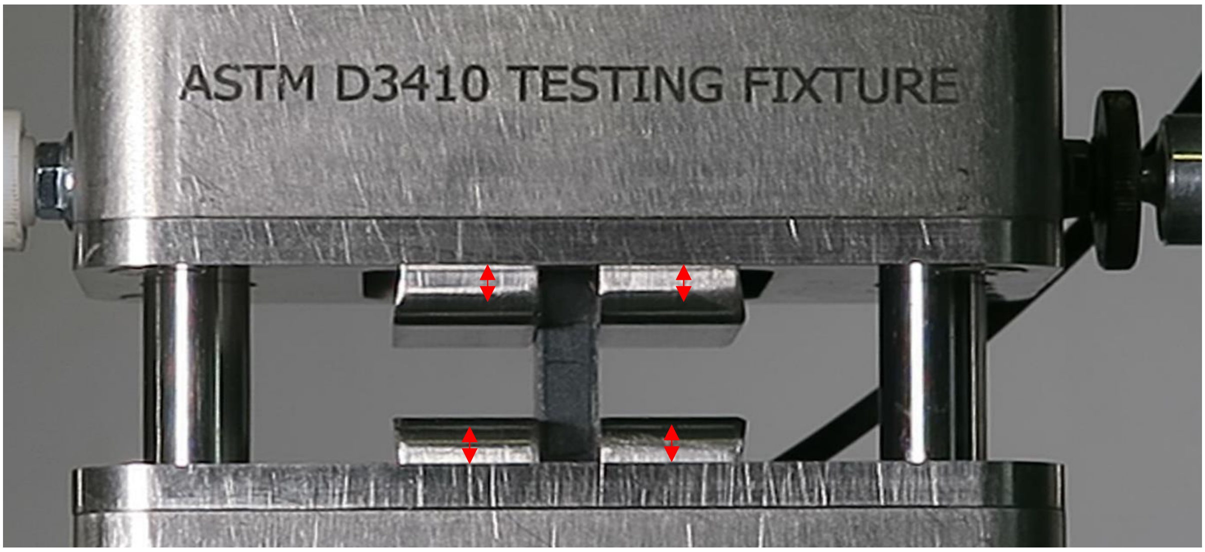


Figure 6-1 Failure mechanism XGM

Additionally, an examination was conducted to assess the extent of wedge displacement when the specimen is compressed by 1mm. Figure 6-2 depicts a sectional sketch of the setup without any applied force. The specimen in this figure has an approximate thickness of 6.7mm. Figure 6-3 illustrates the configuration when the specimen is compressed by 1mm. A 1mm compression results in a vertical displacement of the wedges by 3mm.

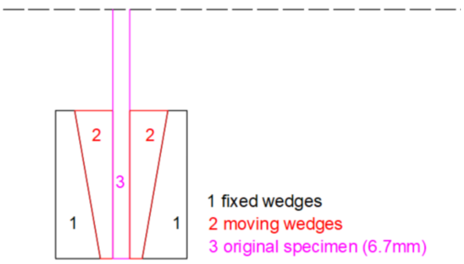


Figure 6-2 Alignment without force

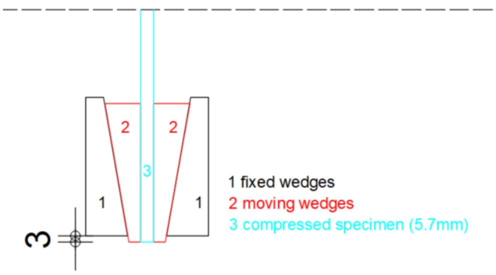


Figure 6-3 Alignment without force

Hence, it can be concluded that only the ultimate strength and stress can be determined through the test, while the strain at failure and E-Modulus cannot be determined. To approximate the E-Modulus and strain at failure in this test, manufacturer's test reports are utilized (as shown in figure 6-4). For the longitudinal direction of the composite sheet piles, the elongation per kN is 0.055%.

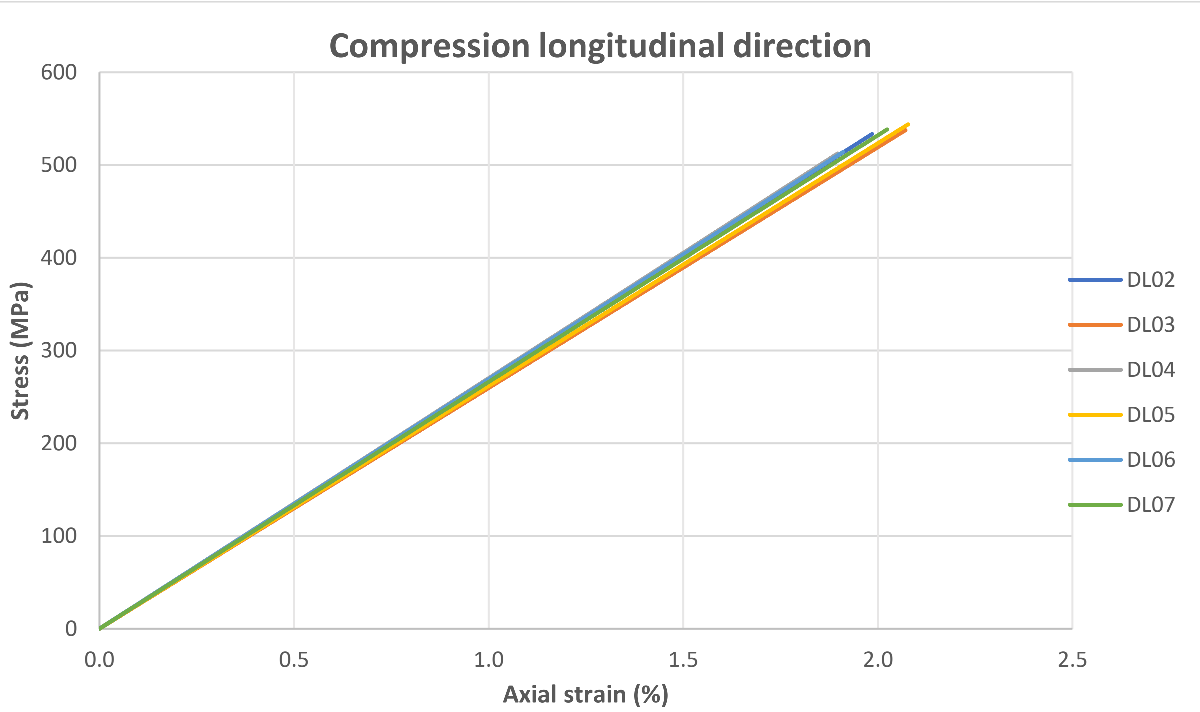


Figure 6-4 Stress strain diagram

6.3 Failure mode

Regarding the samples cut in the longitudinal direction of the material, all specimens exhibited the same failure mechanism. At the first bend in the graphs, the 0/90 fabric experienced delamination. Following this, the fibers in the longitudinal direction still absorbed some additional compressive force. The most pronounced bend in the graph signifies an explosive failure. Compression subjected the fibers in the longitudinal direction to high pressure, leading to an explosive event. Consequently, the failure mode observed aligns with ASTM D3410M – 03, denoted as "XGM," as shown in Figure 6-5. Figure 6-6 depicts all the failed specimens.

Figure 6-5 Steps of failure longitudinal compression

Figure 6-6 Specimens after tests

7 Summary

In summary, the results obtained from the compressive tests yield the following findings, as presented in Table 7-1.

Results compression in longitudinal direction	
Characteristic Strength	34.0 kN
Characteristic Stress	508.4 MPa
Characteristic Maximal Strain	1.87%*
Characteristic E-Modulus	25888 MPa*

table 7-1 Material properties according to compressive test

** Characteristic Maximal Strain and E-Modulus are retrieved from the strain/kN from the manufacturer. This is calculated by*

8 Appendix

8.1 Appendix A – Sample numbering

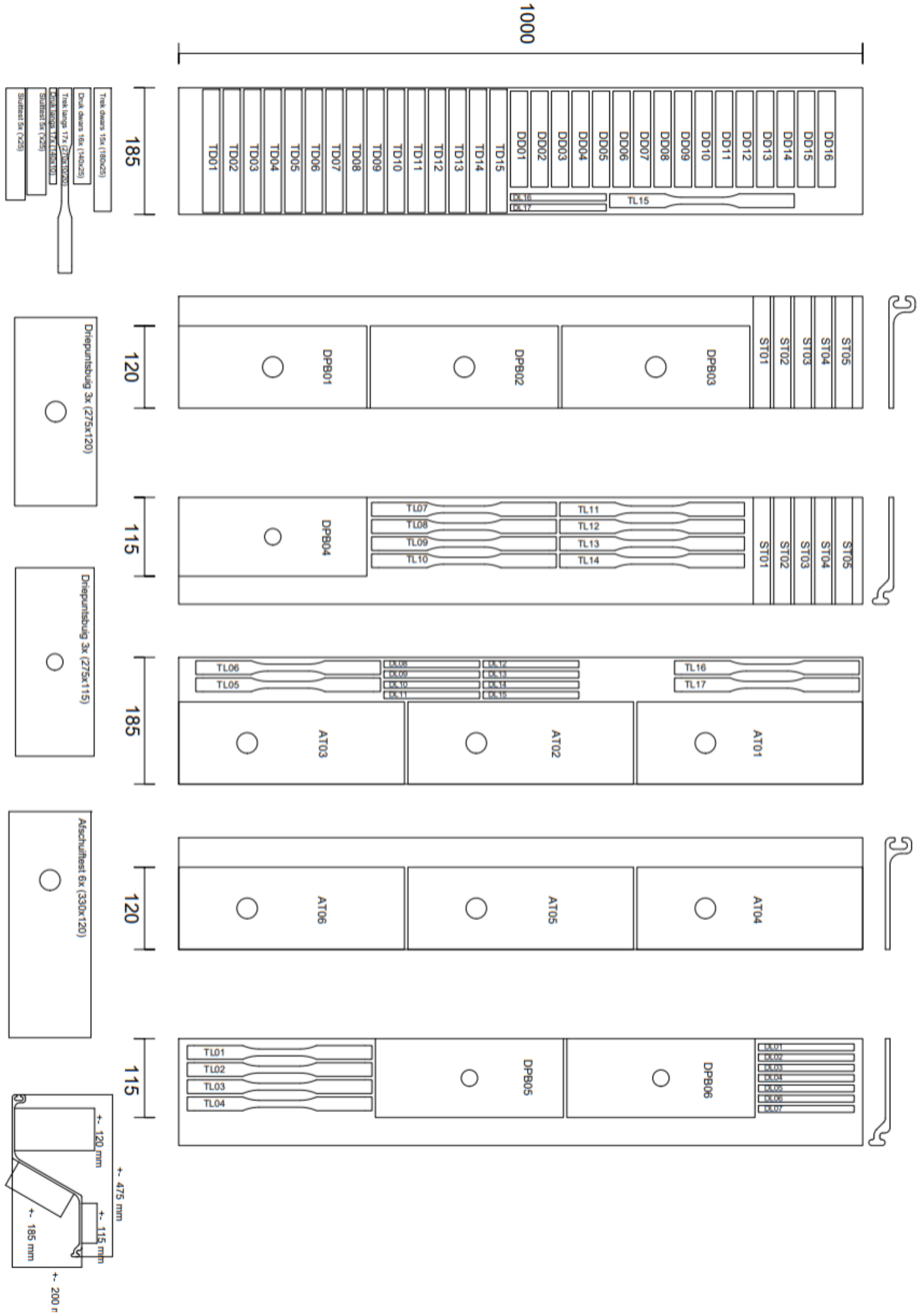


Figure 8-1 Saw plan all samples

Figure 8-2 Samples retrieved from sheet

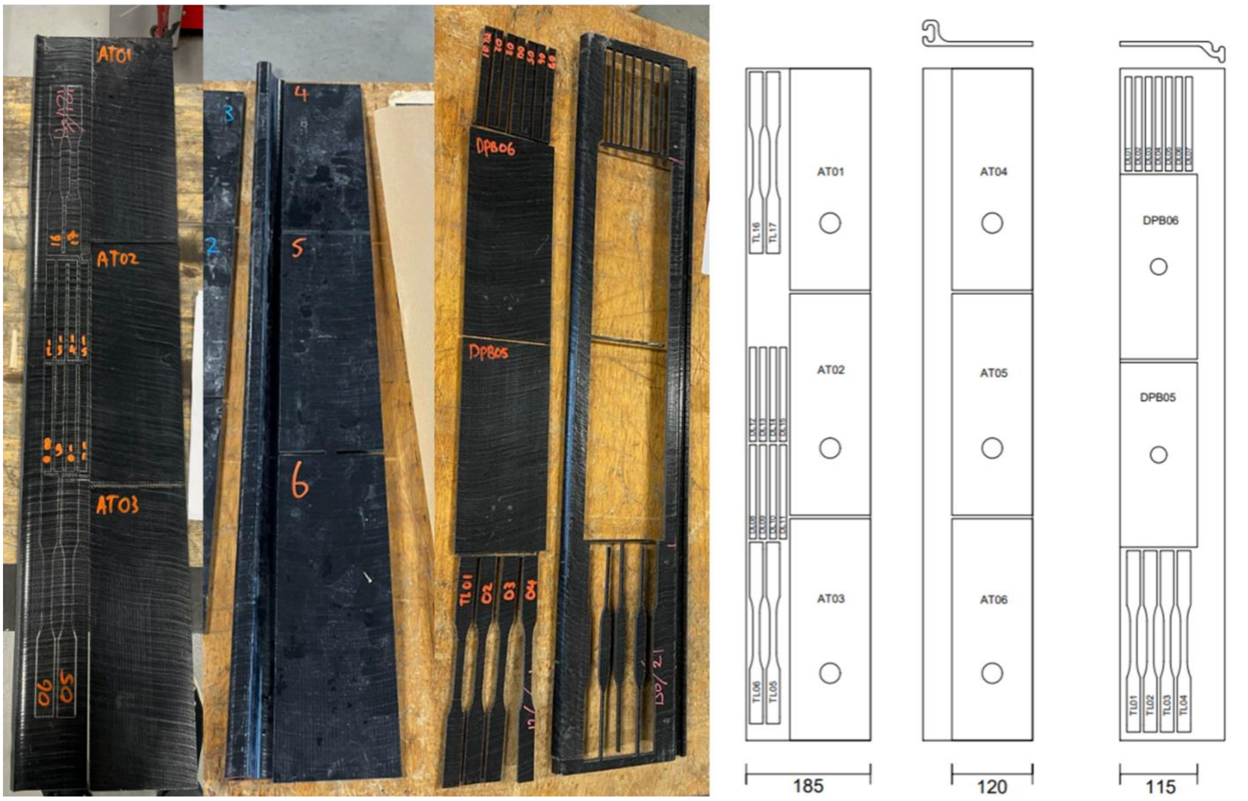
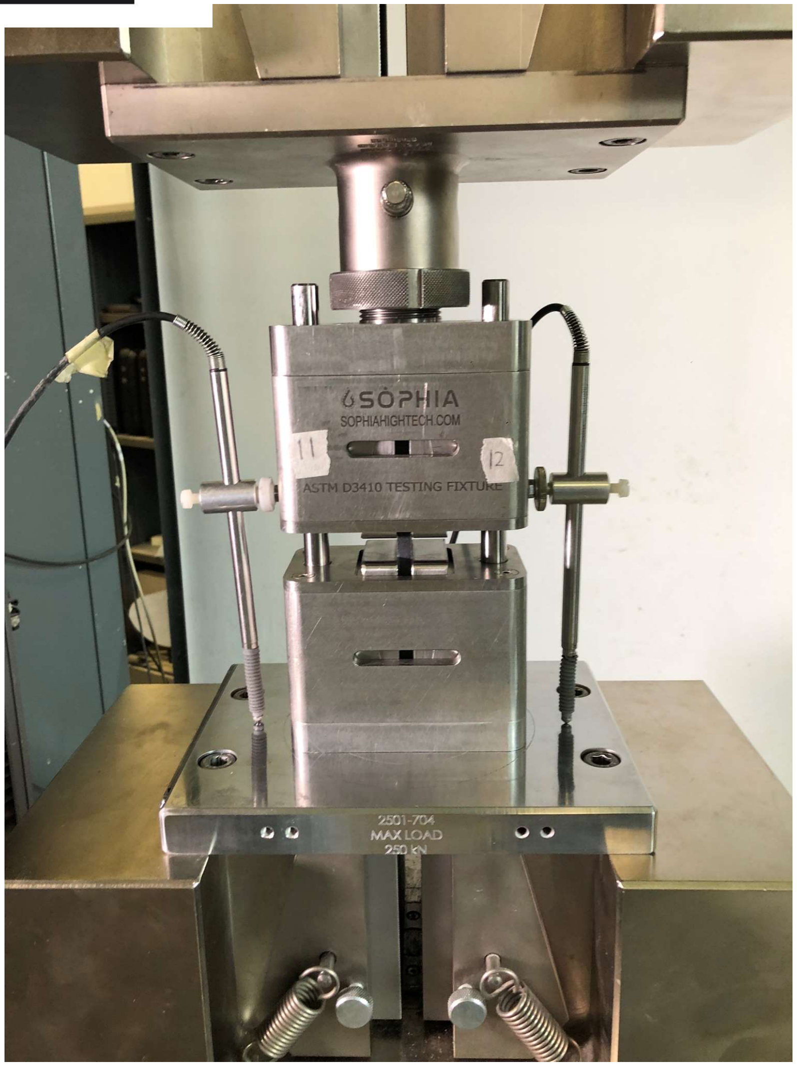
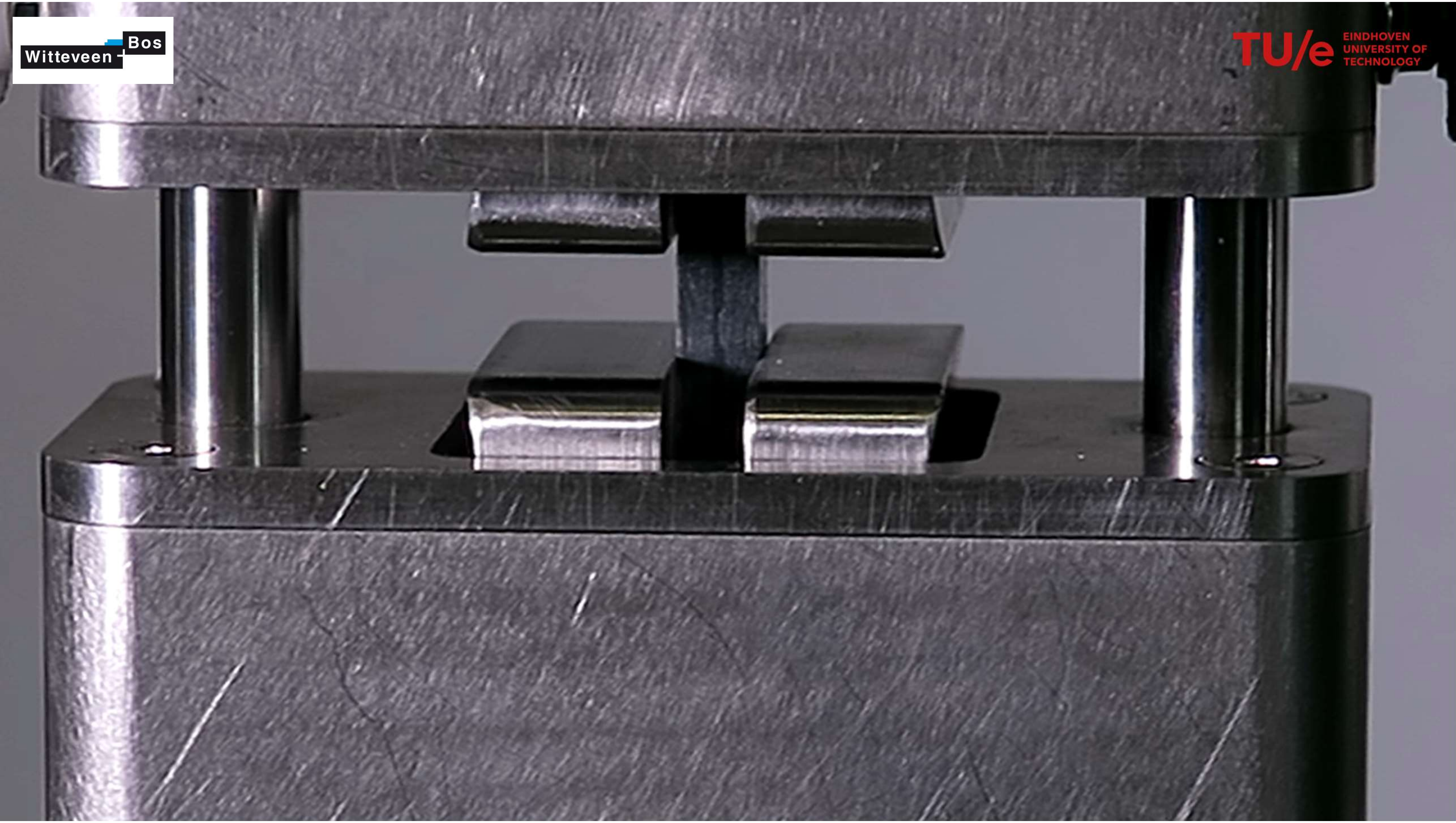


Figure 8-3 Samples retrieved from sheet

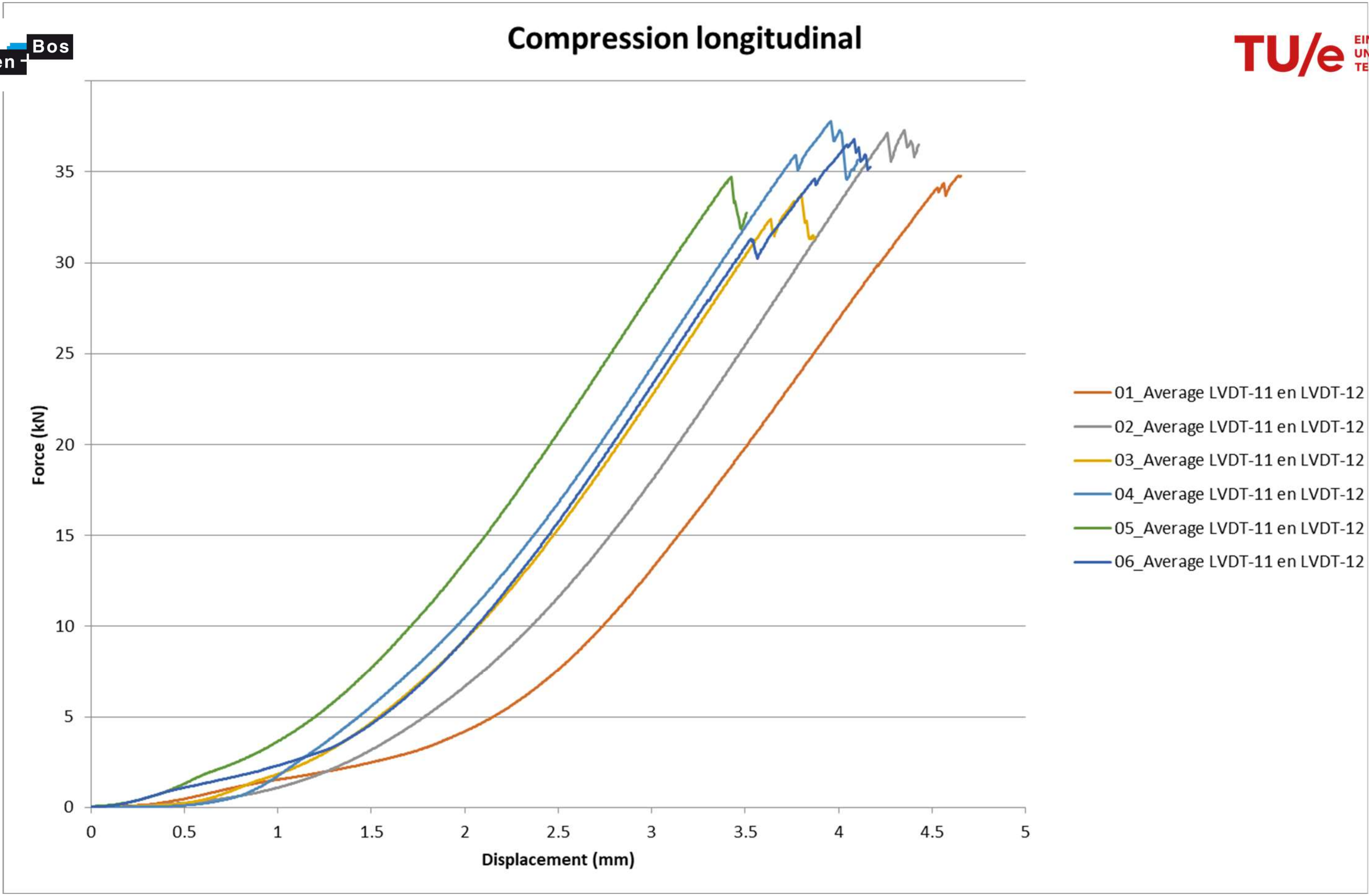
8.2 Appendix B – Presentation results and test

Longitudinal compressive tests composite sheet piles


SOPHIA
SOPHIAHIGHTECH.COM
11
12
ASTM D3410 TESTING FIXTURE
2501-704
MAX LOAD
250 kN


Witteveen Bos
TU/e
EINDHOVEN
UNIVERSITY OF
TECHNOLOGY


Witteveen + Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
ASTM D3410 TESTING FIXTURE


Compression longitudinal
Force (kN)
0
5
10
15
20
25
30
35
Displacement (mm)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
01_Average LVDT-11 en LVDT-12
02_Average LVDT-11 en LVDT-12
03_Average LVDT-11 en LVDT-12
04_Average LVDT-11 en LVDT-12
05_Average LVDT-11 en LVDT-12
06_Average LVDT-11 en LVDT-12

5.4 Appendix D – Report Transverse compressive tests

Transverse compressive tests composite sheet piles

ASTM D3410M - 03

Projectnaam: Opwaardering Twentekanalen
Opdrachtgever: Rijkswaterstaat GPO
Opdrachtnemer: Combinatie Van Oord, Hakkers, Beens
Onderaannemer: Witteveen+Bos, TU/e, Dept. of Built Environment

Status: Definitief
Revisie: 1.0 – 22-03-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0	Prepared by			
	Checked by			
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0		Final Version

Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date tested:	22-03-2023
Test standards:	ASTM D3410M - 03
Material:	E-glass, polyester
Specimen type:	ASTM D3410M - 03
Pre-treatment:	21 °C / 45-50% RV
Machine:	Instron 5985
Pre-load:	0 MPa
Test speed:	1.3 mm/min
Gage length, standard travel:	10 mm

Inhoudsopgave

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

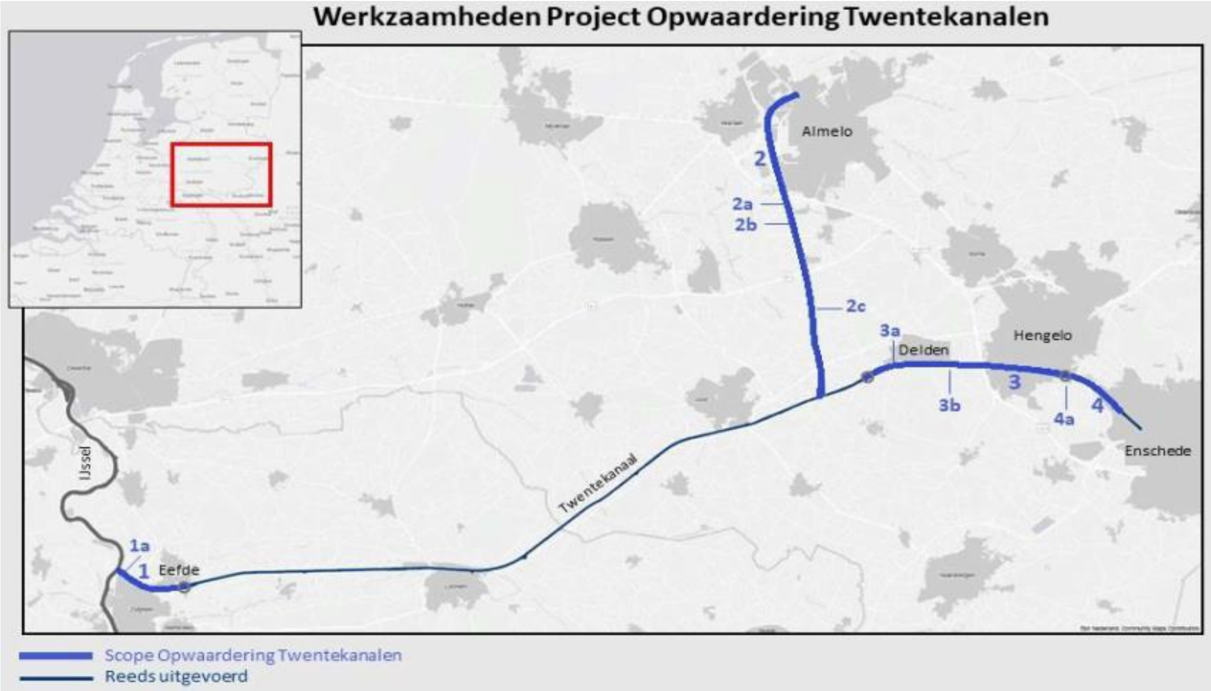


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometer points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **compression tests in transverse direction** conducted on the composite sheet piles.

2 Test and material

This paper will present the results obtained from compression tests conducted on composite sheet piles. The testing methodology adheres to ASTM D3410M_2003 standards, including the dimensions of the compressive tests. The material is tested perpendicular (transverse) to the fiber direction.

These sheet piles are constructed from pultruded glass fiber polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in³/ft	703.22	cm³/m
Moment of Inertia	54.01	in⁴/ft	7375.52	cm⁴/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in²	47.94	cm²
Standard Color	Graphite Gray			

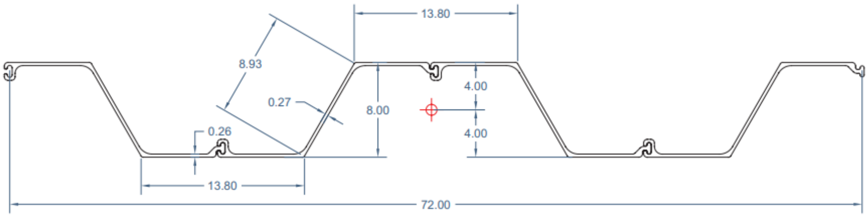
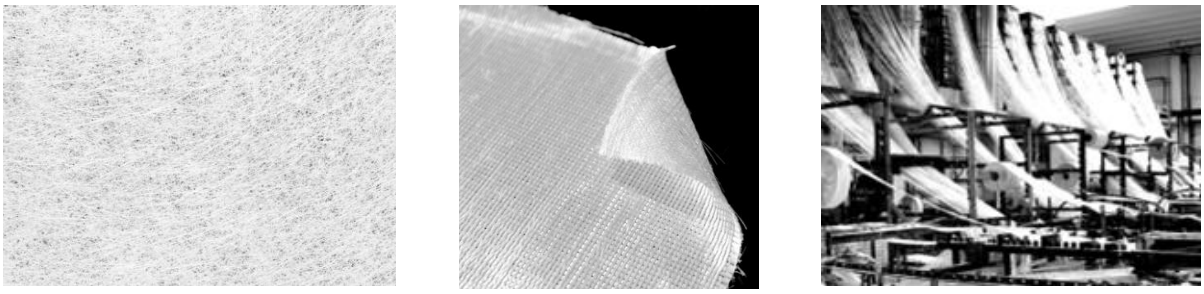


Figure 2-1 Superloc Series 1580

The glass fiber volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibers on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament | 0/90 Fabric | 0 Direction

Figure 2-2 Visual representation glass fibers used

3 Preparation and equipment used

The specimen dimensions were obtained from ASTM D3410M - 03, as shown in Table 3-1. Appendix A contains the sawing plan for the samples, which were extracted from the sheet pile elements. Only the samples labeled 'DDxx' are relevant for this test. These specimen samples were prepared using waterjet cutting at the Equipment and Prototype Center of the Technical University in Eindhoven. Figures 8-1, 8-2, and 8-3 in Appendix A depict the locations from which the samples were extracted from the sheet pile. No specific consolidation methods were applied afterward, and the samples were stored in the test lab. No nondestructive test methods were employed prior to this test.

DDxx

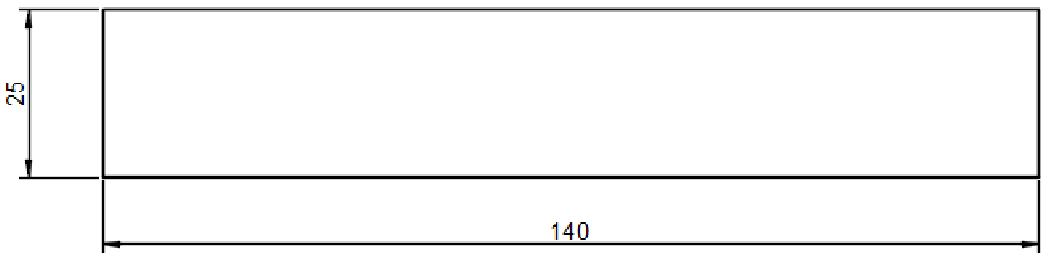


Table 3-1: Sample dimensions

For this test, an Instron 5985 machine manufactured on May 15, 2014, with a capacity of 250kN was utilized. The machine underwent its most recent calibration on February 14, 2022, by NMI Certin. Data was directly collected from the Instron machine using computer software to measure the material strain. The data was then exported as CSV files, which were subsequently imported into Excel for data processing.

The raw data included Time, Force, Displacement, and Compressive Stress. The input data for the computer software consisted of Length, Thickness, and Width. Width and thickness were measured at three points for each sample, and the results are presented in Table 3-2.

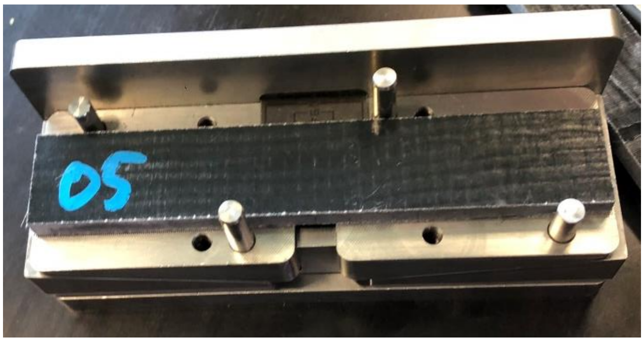
Compression transverse									
	Edge	Middle	Edge		Edge	Middle	Edge		
Sample	Width (mm)	Width (mm)	Width (mm)	**Average width (mm)**	Thickness (mm)	Thickness (mm)	Thickness (mm)	**Average thickness (mm)**	**Average area (mm2)**
DD01	25.07	25.12	25.20	**25.13**	6.65	6.63	6.71	**6.66**	**166.61**
DD02	24.95	24.94	24.77	**24.89**	6.65	6.60	6.58	**6.61**	**164.25**
DD03	25.05	25.16	25.15	**25.12**	6.59	6.62	6.64	**6.62**	**166.29**
DD04	25.02	24.93	24.96	**24.97**	6.76	6.62	6.64	**6.67**	**165.30**
DD05	25.14	25.16	25.20	**25.17**	6.66	6.65	6.64	**6.65**	**167.36**
DD06	25.08	24.98	25.02	**25.03**	6.70	6.59	6.56	**6.62**	**164.93**

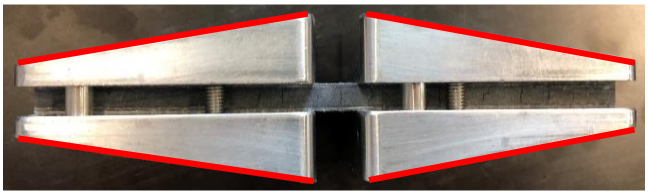
Table 3-2: Measured transverse sample dimensions

A total of 6 compressive tests were conducted in the transverse direction of the material. A testing speed of 1.3 mm/min was employed. For testing, we utilized a Sophia gripper ASTM D 3410 in addition to the Precision Manual Wedge Grips model number 2716-030 from the Instron machine.

Initially, the samples were placed in the Sophia gripper, as shown in Figures 3-1 and 3-2. Subsequently, the Sophia gripper was aligned within the Instron machine using the system illustrated in Figure 3-3. Figure 3-3 also displays two Linear Variable Differential Transformers (LVDTs) indicated by yellow ovals on both sides of the Instron test alignment. These LVDTs are from the Instron 2601 series and were used to measure the displacement of the specimen.

No tabs were used during testing, as they were deemed unnecessary since the failure results aligned with our initial expectations for the initial tests. The laboratory conditions maintained a relative humidity (RH) of 40-45% and a temperature of approximately 21 degrees Celsius. No other specific environmental conditions were applied during the tests or the storage of the samples.





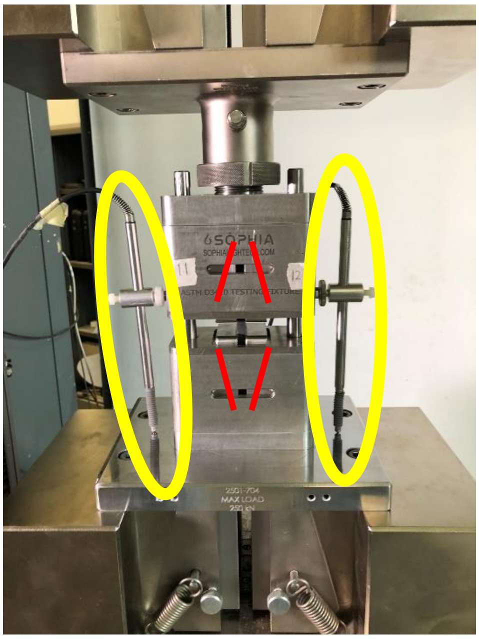


Figure 3-1 Sample placed in Sophia gripper (top left)
Figure 3-2 Sample placed in Sophia gripper (bottom left)
Figure 3-3 Sophia gripper aligned in the Instron (right)

4 Results

Figure 4-1 presents the relationship between force and displacement in the compressive test conducted in the transverse direction. The results indicate that the maximum force before failure in the transverse direction ranges between 10.6kN and 14.7kN. Table 4-1 provides the force/displacement graphs for each sample in the transverse direction.

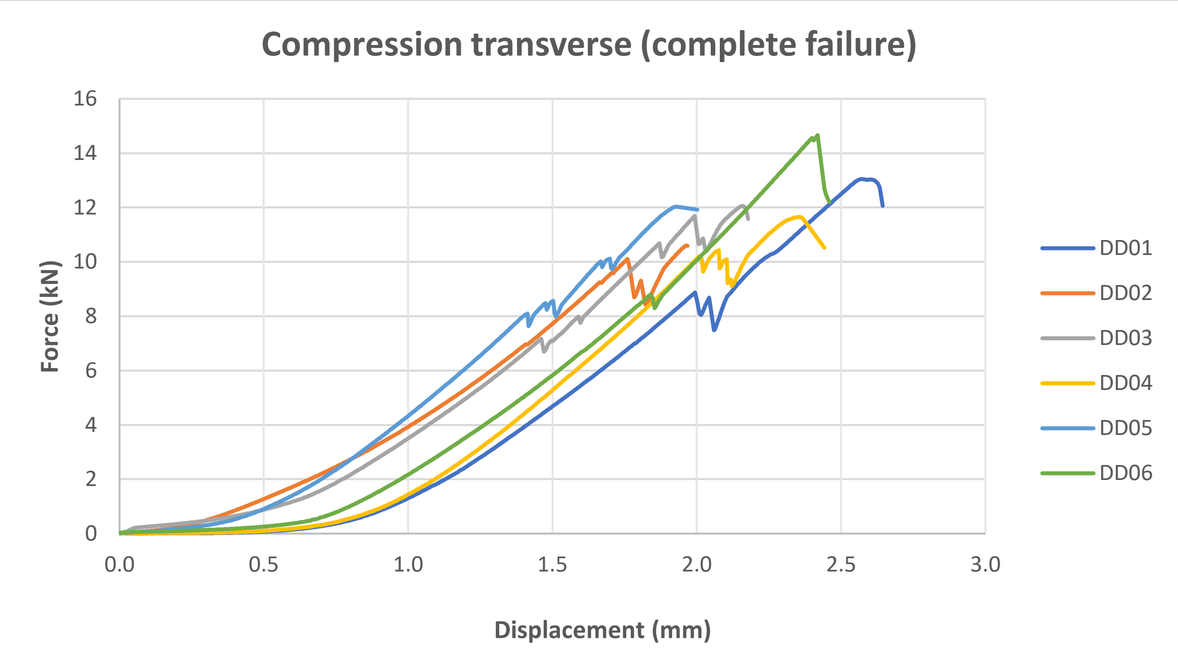


Figure 4-1 Force-displacement of the compressive test in transverse direction (complete failure)

Figure 4-1 illustrates the maximum force reached just before total failure. In addition to complete failure, a phenomenon that is more commonly observed in composite materials occurs: the "first ply failure." This "first ply failure" occurred in samples DD01, DD02, DD03, and DD04, with these failures occurring within the range of 8.7kN to 11.7kN. These specific failures are depicted in Figure 4-2.

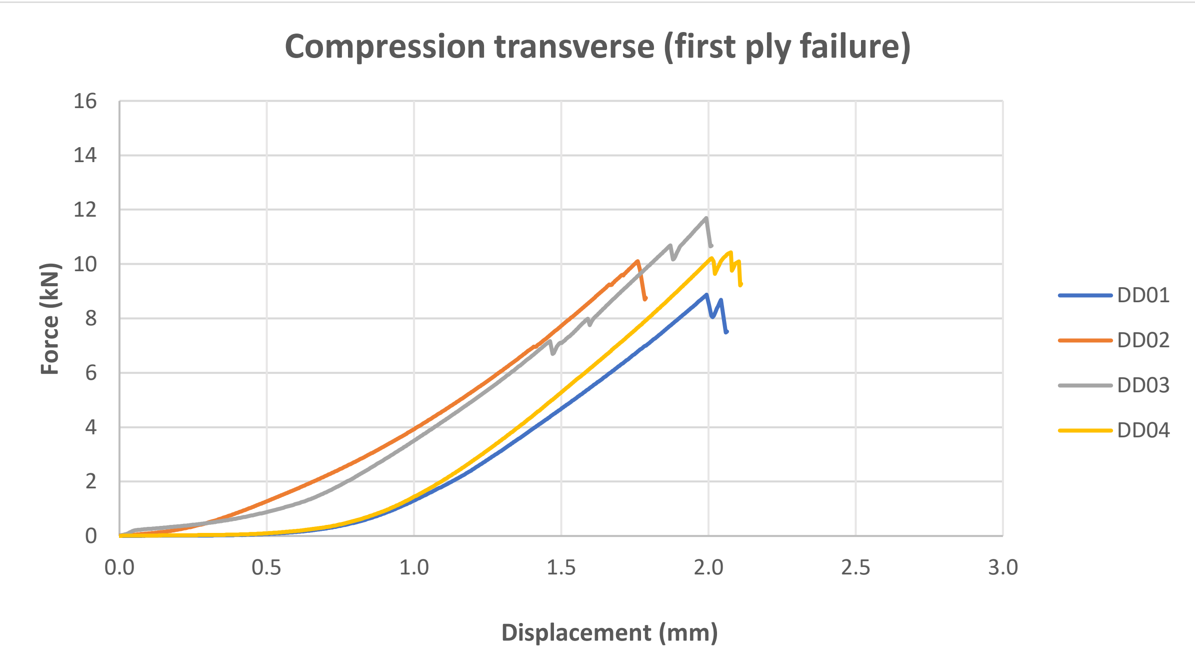
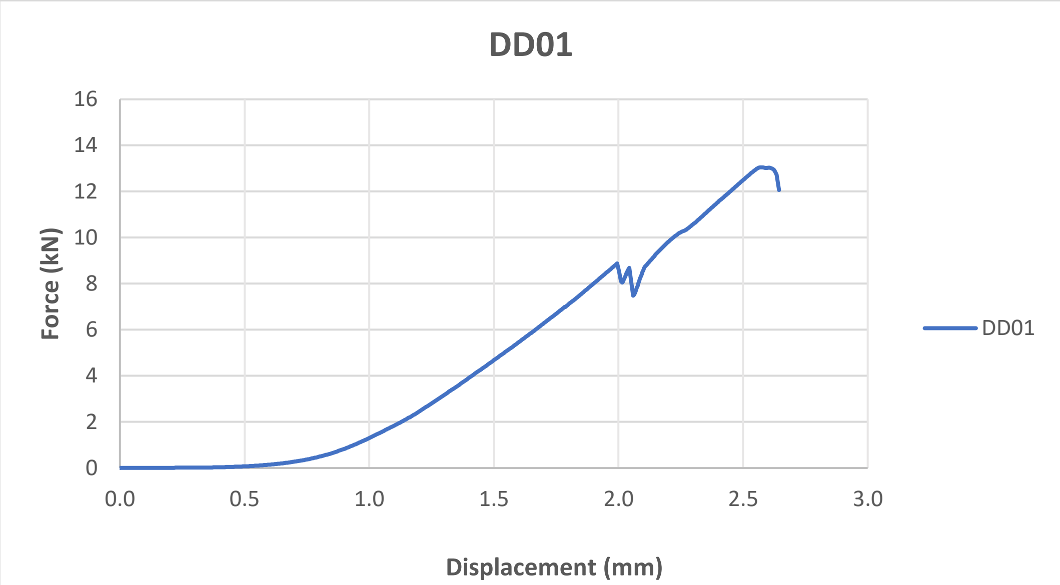
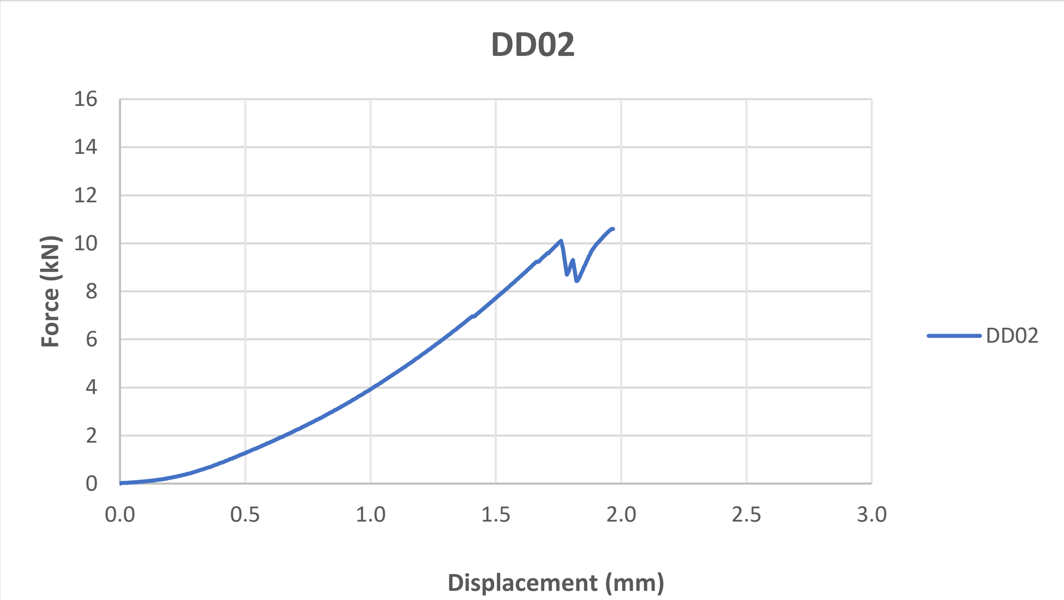
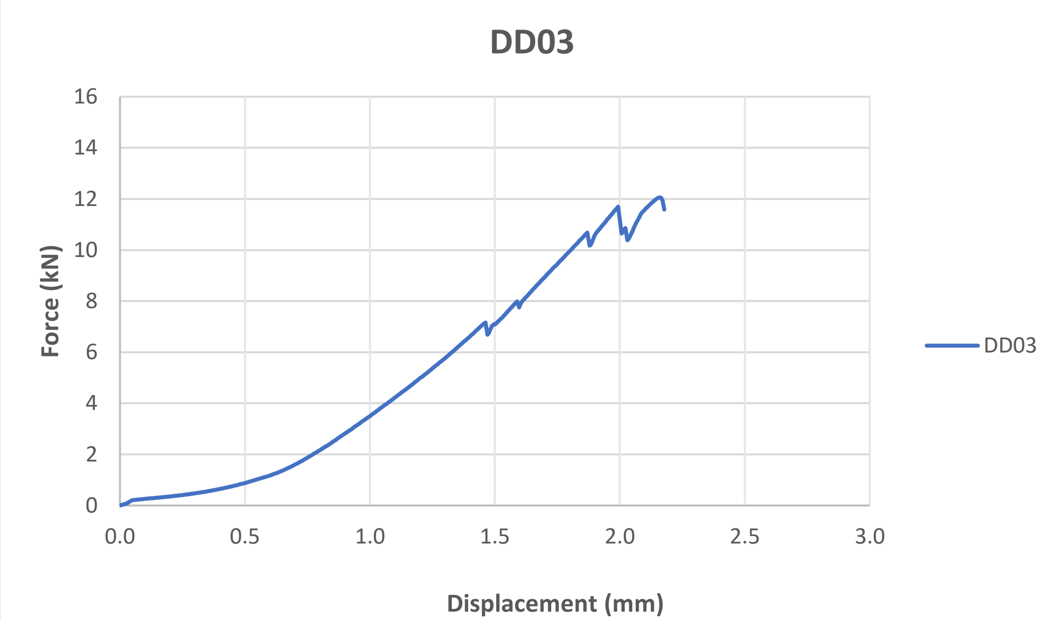
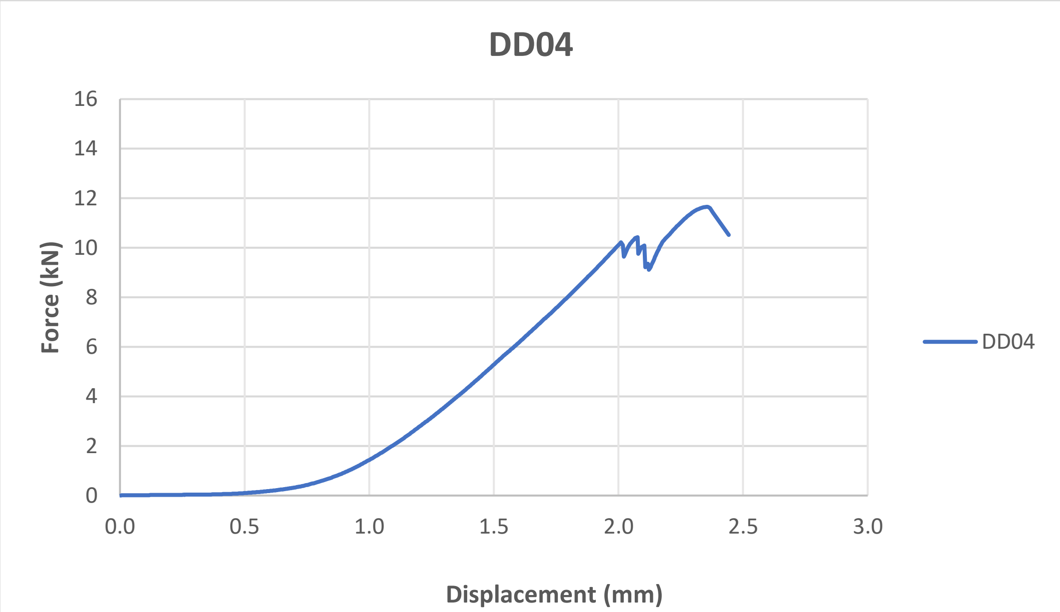


Figure 4-2 Force-displacement of the compressive test in transverse direction (first ply failure)

<table>
<tr><th>Test:</th><th>Force/Displacement graphs</th></tr>
<tr><td>DD 01</td><td>


</td></tr>
<tr><td>DD 02</td><td>


</td></tr>
</table>

DD 03	DD03 Force (kN) 0 2 4 6 8 10 12 14 16 0.0 0.5 1.0 1.5 2.0 2.5 3.0 Displacement (mm) DD03
DD 04	DD04 Force (kN) 0 2 4 6 8 10 12 14 16 0.0 0.5 1.0 1.5 2.0 2.5 3.0 Displacement (mm) DD04

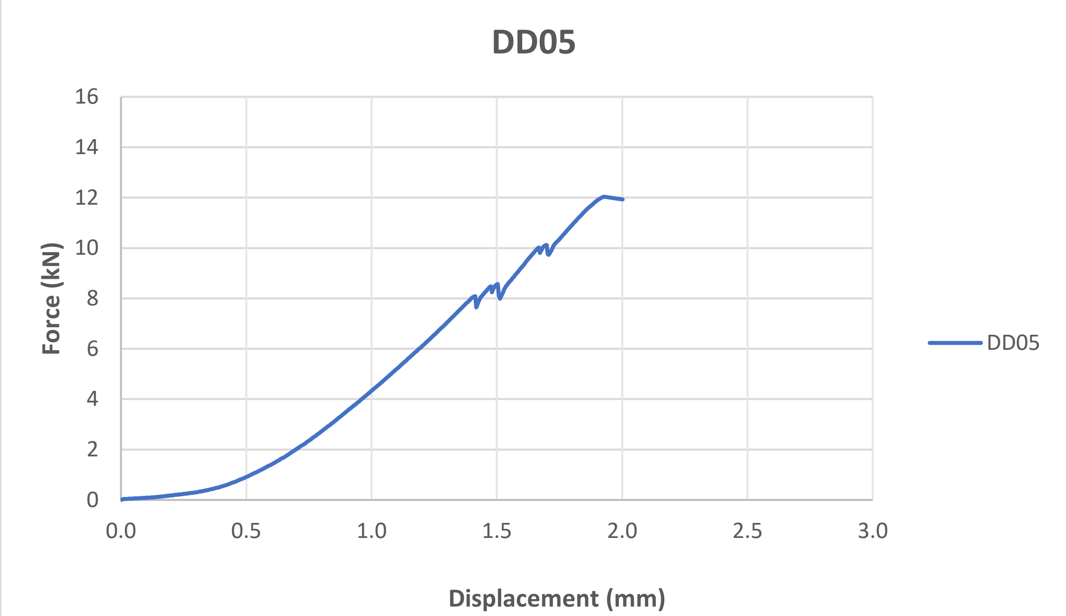
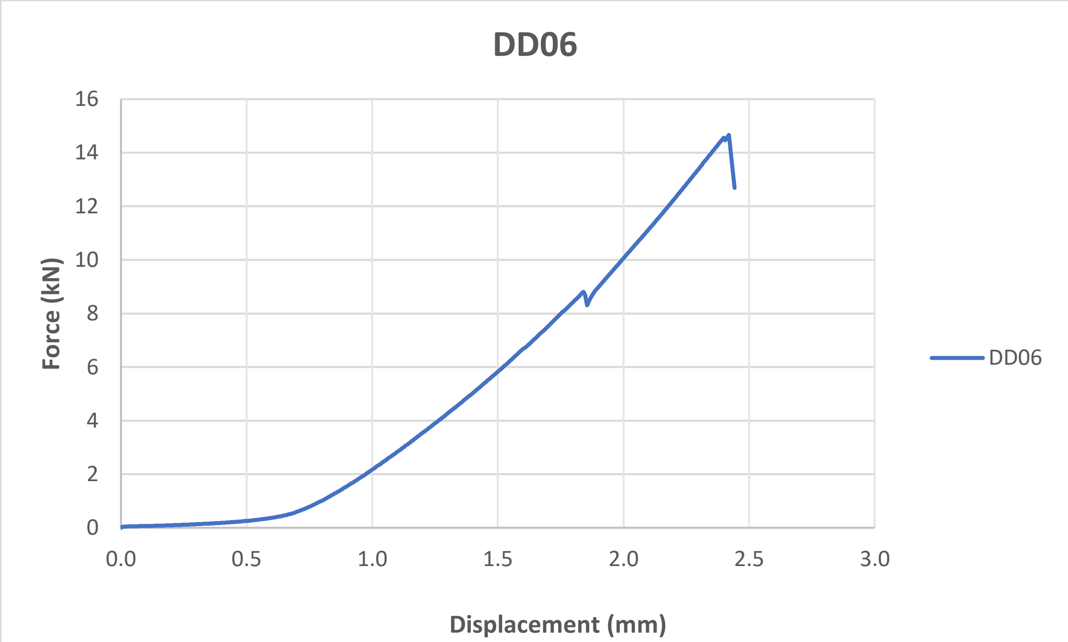
DD 05	
DD 06	

Table 4-1: Force/Displacement graphs transverse direction

5 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value

n = number of tests

V_x = Which is the coefficient of variation $V_x = S_x/m_x$

S_x = Standard deviation

m_x = average value

k_n = Static factor which can be calculated with $k_n = K* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.

K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 5-1: k_n values

6 Transverse compressive strength

6.1 Ultimate compressive strength and stress

Table 6-1 includes the ultimate compressive strength and stress values for each specimen tested in the transverse direction of the material.

Individual Strength and Stress

Sample	Max Force (kN)	Deviation (kN)	Max Stress (MPa)	Deviation (MPa)
DD01	13,05	0,71	78,0	3,75
DD02	10,60	-1,74	64,4	-9,77
DD03	12,06	-0,29	72,5	-1,71
DD04	11,65	-0,69	70,0	-4,25
DD05	12,04	-0,31	71,9	-2,31
DD06	14,66	2,32	88,5	14,29
Average (kN)	12,34	**Average (MPa)**	74,21	
Standard deviation (kN)	1,26	**Standard deviation (MPa)**	7,53	
Coefficient of variation (%)	10,23	**Coefficient of variation (%)**	10,14	
K	1,645	**K**	1,645	
kn	1,777	**kn**	1,777	
n	6	**n**	6	
Rk(kN)	10,10	**Rk(MPa)**	60,84	

Table 6-1: Individual strength and stress transverse direction

6.2 E-Modulus and Strain at failure

The E-Modulus and Strain at failure must be determined following ASTM D3410M. In these tests, a Sophia gripper, as previously described in this document, was utilized for the compressive tests. This gripper is intended for specimens with precise thicknesses ranging from 1 to 10 mm. However, the composite sheet piles do not possess an exact thickness (for instance, not precisely 4 mm). As a result, the wedges of the Sophia gripper did not fit entirely within the gripper (see figure 6-1), leading to wedges displacement.

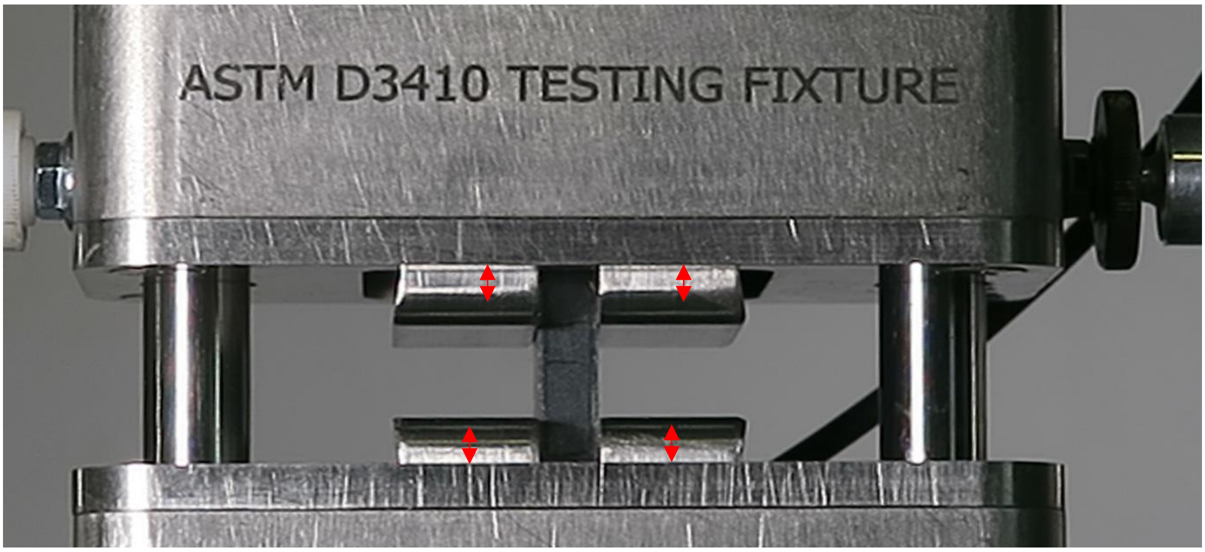


Figure 6-1 Failure mechanism XGM

Additionally, an examination was conducted to assess the extent of wedge displacement when the specimen is compressed by 1mm. Figure 6-2 depicts a sectional sketch of the setup without any applied force. The specimen in this figure has an approximate thickness of 6.7mm. Figure 6-3 illustrates the configuration when the specimen is compressed by 1mm. A 1mm compression results in a vertical displacement of the wedges by 3mm.

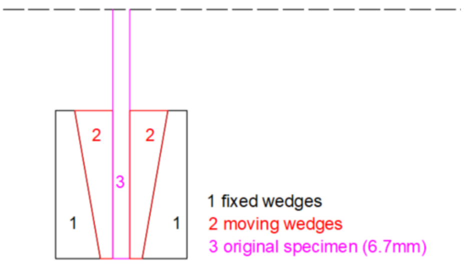


Figure 6-2 Alignment without force

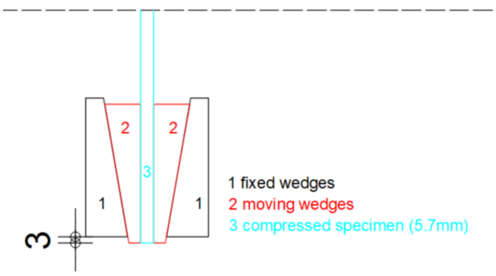


Figure 6-3 Alignment without force

Hence, it can be concluded that only the ultimate strength and stress can be determined through the test, while the strain at failure and E-Modulus cannot be determined. To approximate the E-Modulus and strain at failure in this test, manufacturer's test reports are utilized (as shown in figure 6-4). For the transverse direction of the composite sheet piles, the elongation per kN is 0.174%.

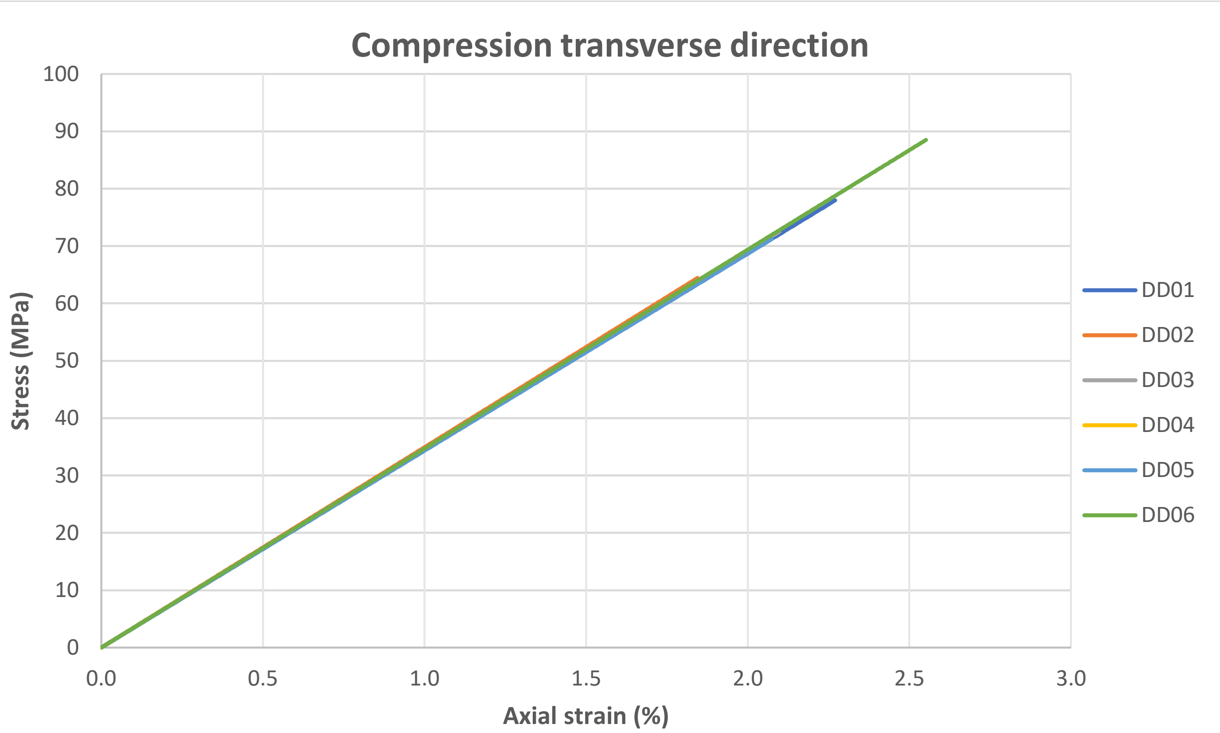


Figure 6-4 Stress strain diagram

6.3 Failure mode

The samples cut for the transverse specimens exhibited the same mode of failure. Figure 6-5 illustrates the three stages of failure.

Step 1 (left picture): Specimen without any failure.

Step 2 (middle picture): Initial ply failure. In this stage, the 0/90 mats on the outer surface of the specimen first delaminate and almost immediately 'crack.' It is crucial to consider this initial ply failure when calculating compression in the transverse direction for composite sheet piles, especially because it is a thermoset material. This means that once the 0/90 mats 'crack,' the composite sheet piles will never return to their original state.

Step 3 (right picture): Complete failure. Adjacent to the 0/90 mats, the entire material has now failed or cracked.

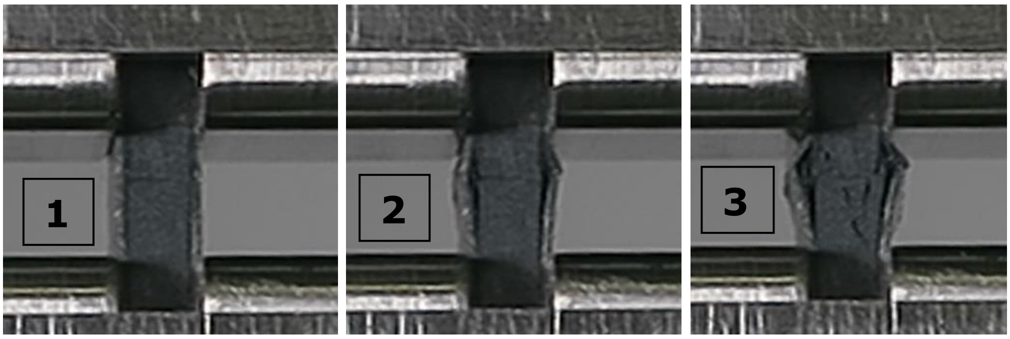


Figure 6-5 Steps of failure transverse compression

Connecting the initial ply failure, as shown in the ASTM, to the standard failure mechanism is challenging. Hence, the failure code used is "OGM." Figure 6-6 showcases all the failed specimens.

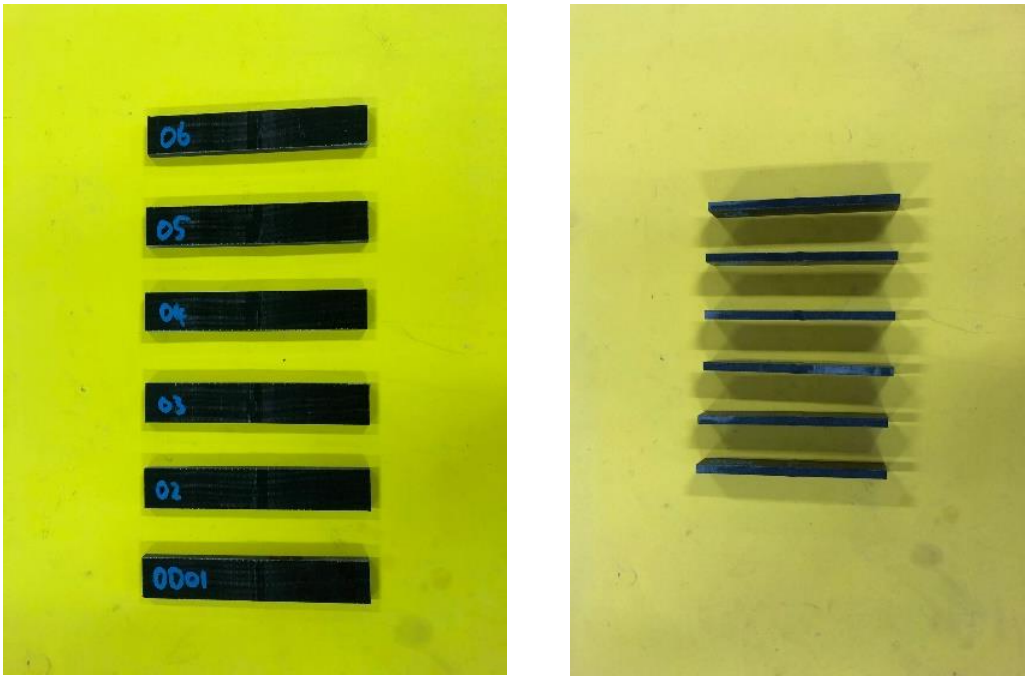


Figure 6-6 Specimens after tests

7 Summary

In summary, the results obtained from the compressive tests yield the following findings, as presented in Table 7-1.

Results compression strength transverse direction	
Characteristic Strength	10.1 kN
Characteristic Stress	60.8 MPa
Characteristic Maximal Strain	1.75%*
Characteristic E-Modulus	8605 MPa*

table 7-1 Material properties according to compressive test

** Characteristic Maximal Strain and E-Modulus are retrieved from the strain/kN from the manufacturer. This is calculated by*

8 Appendix

8.1 Appendix A – Sample numbering

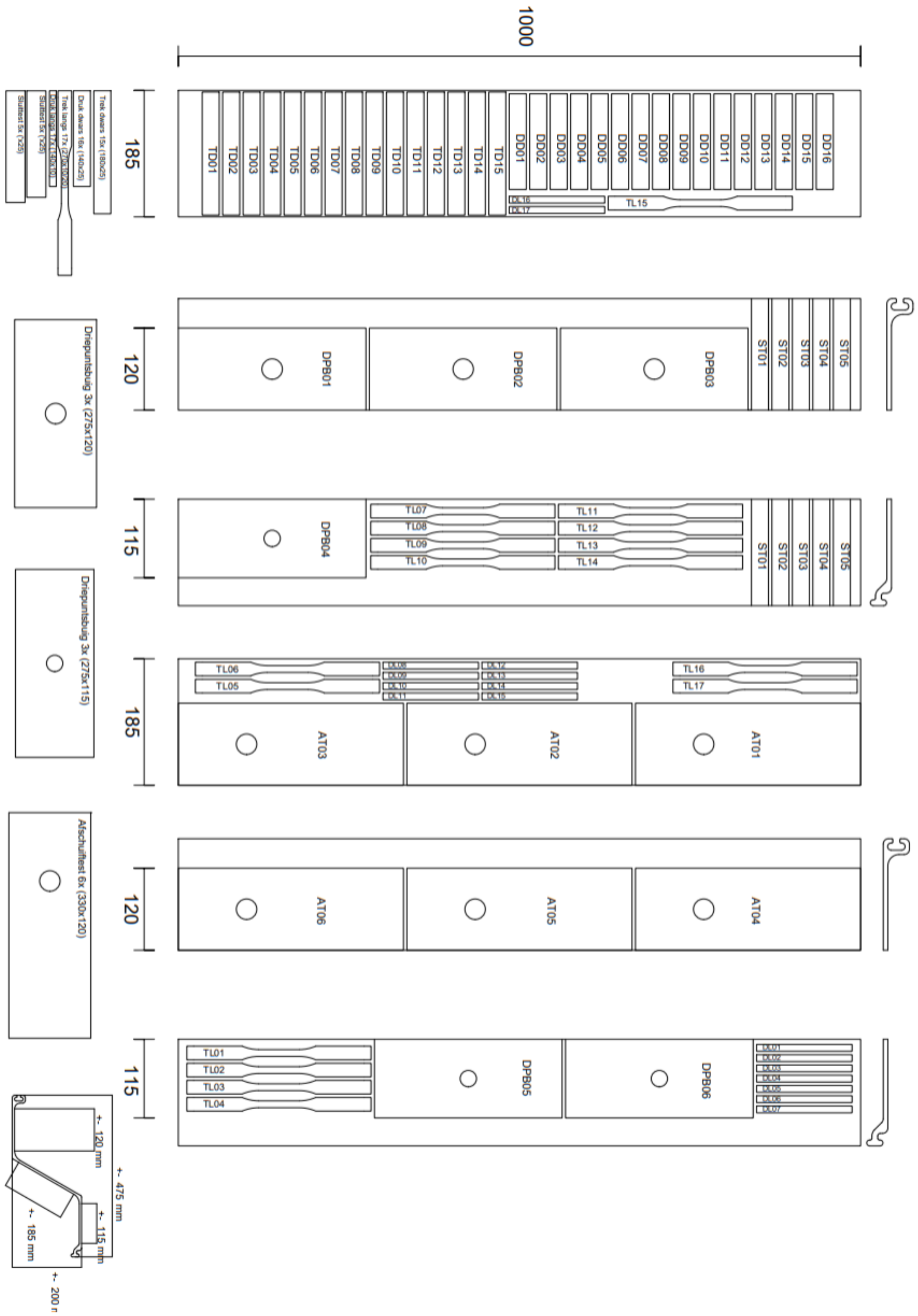


Figure 8-1 Saw plan all samples

Figure 8-2 Samples retrieved from sheet

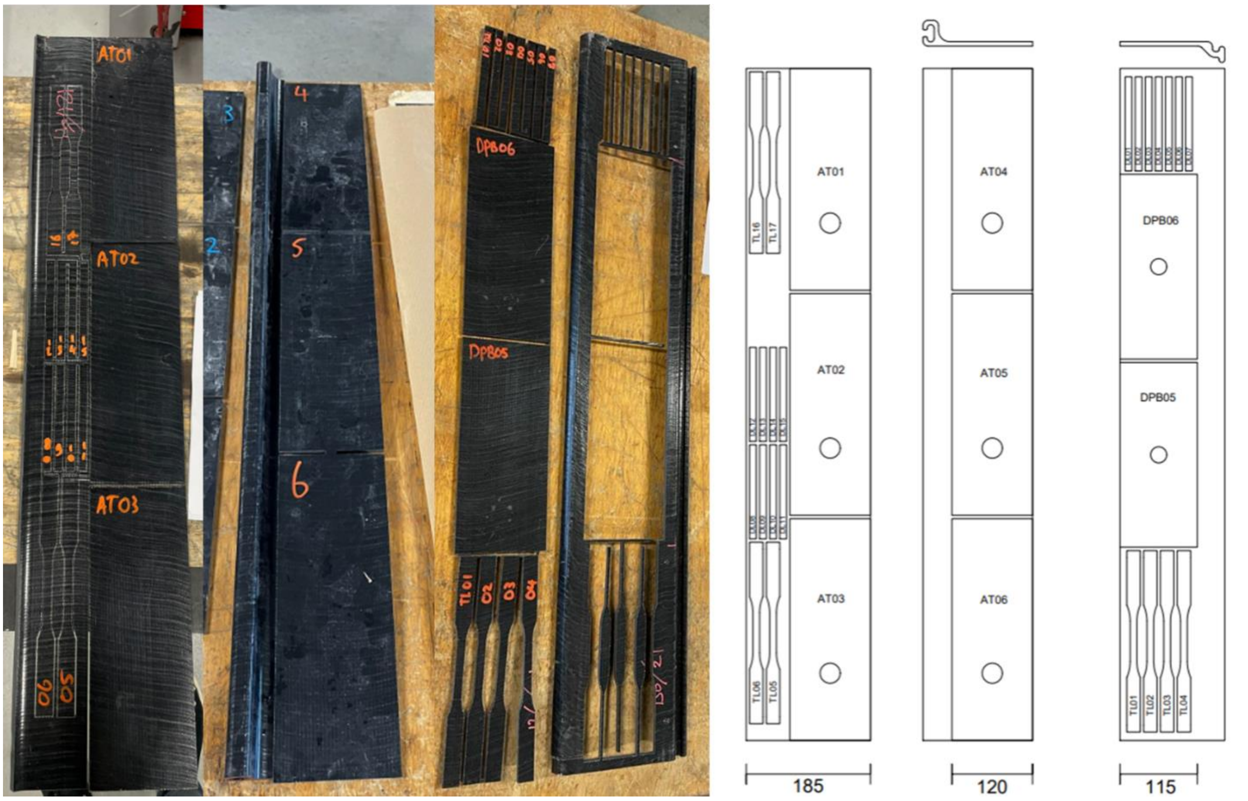
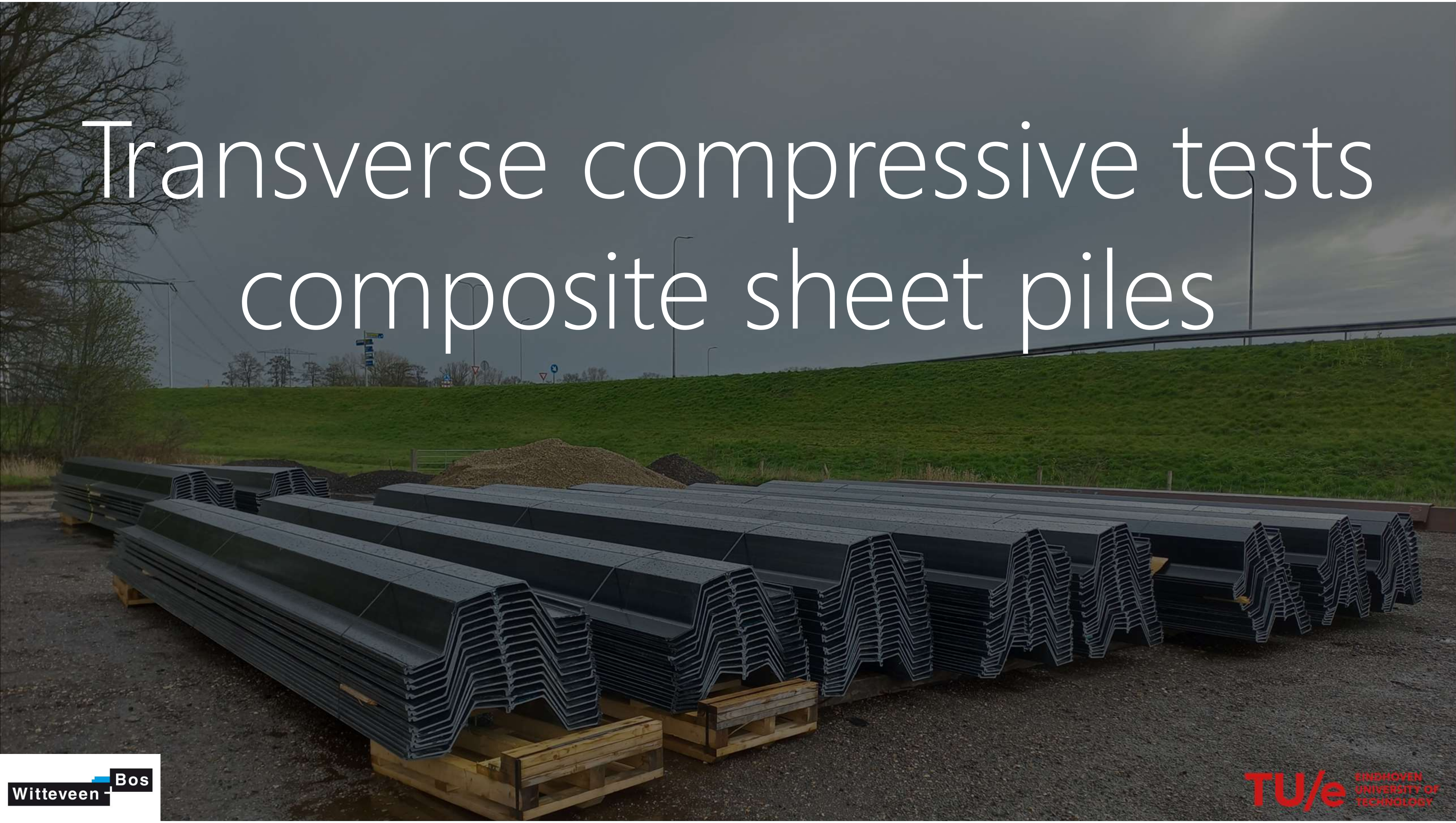


Figure 8-3 Samples retrieved from sheet

8.2 Appendix B – Presentation results and test

Transverse compressive tests composite sheet piles



Witteveen + Bos

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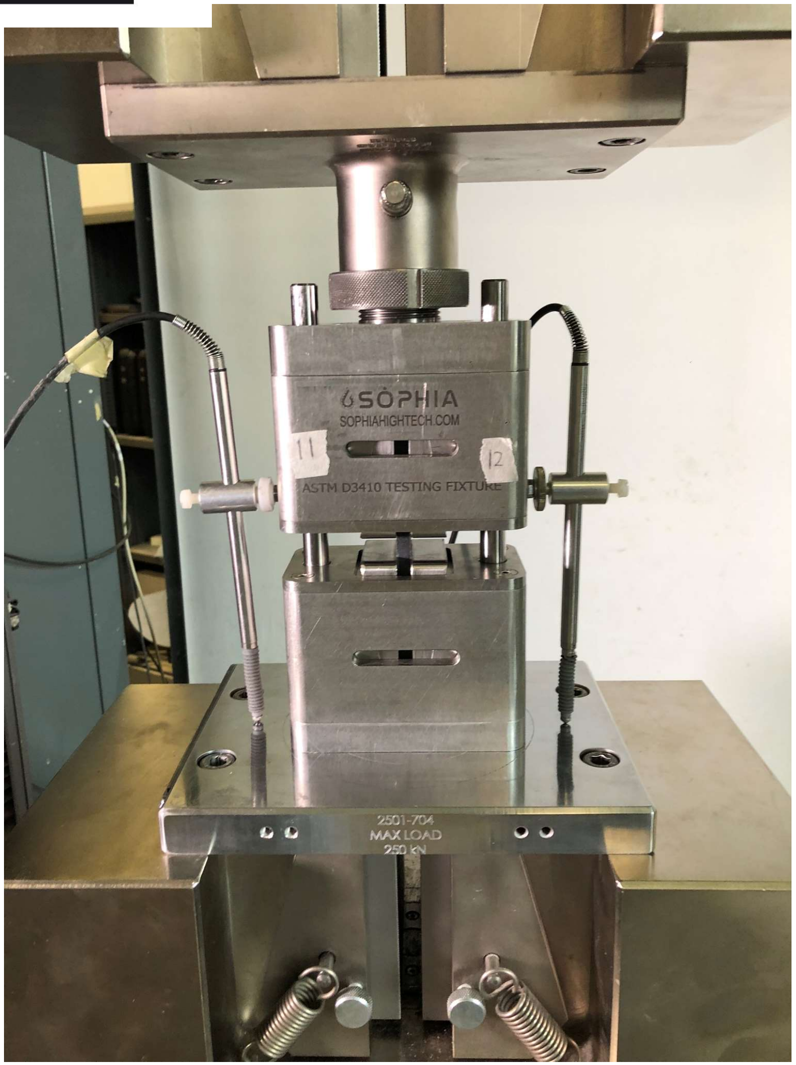
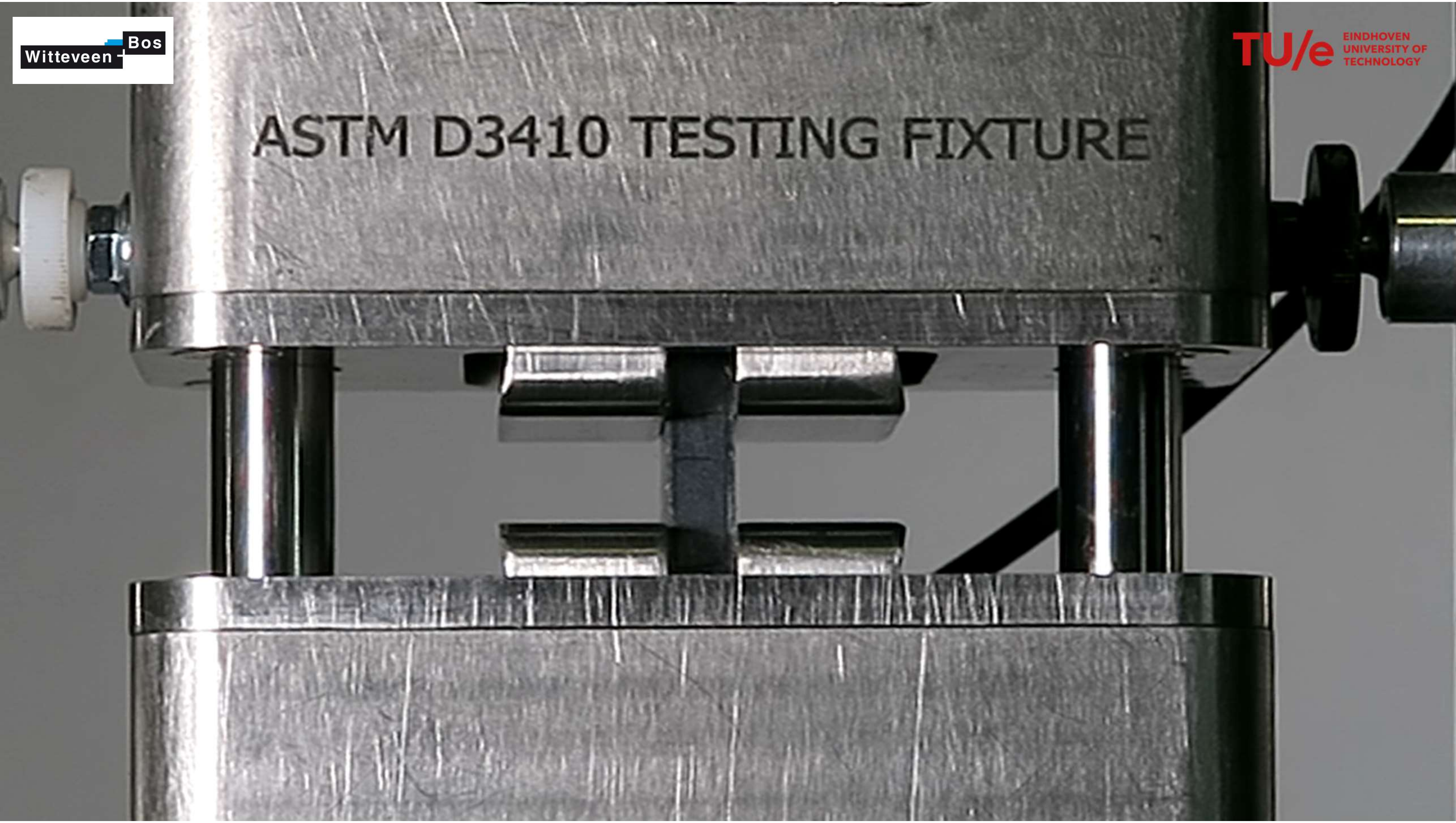
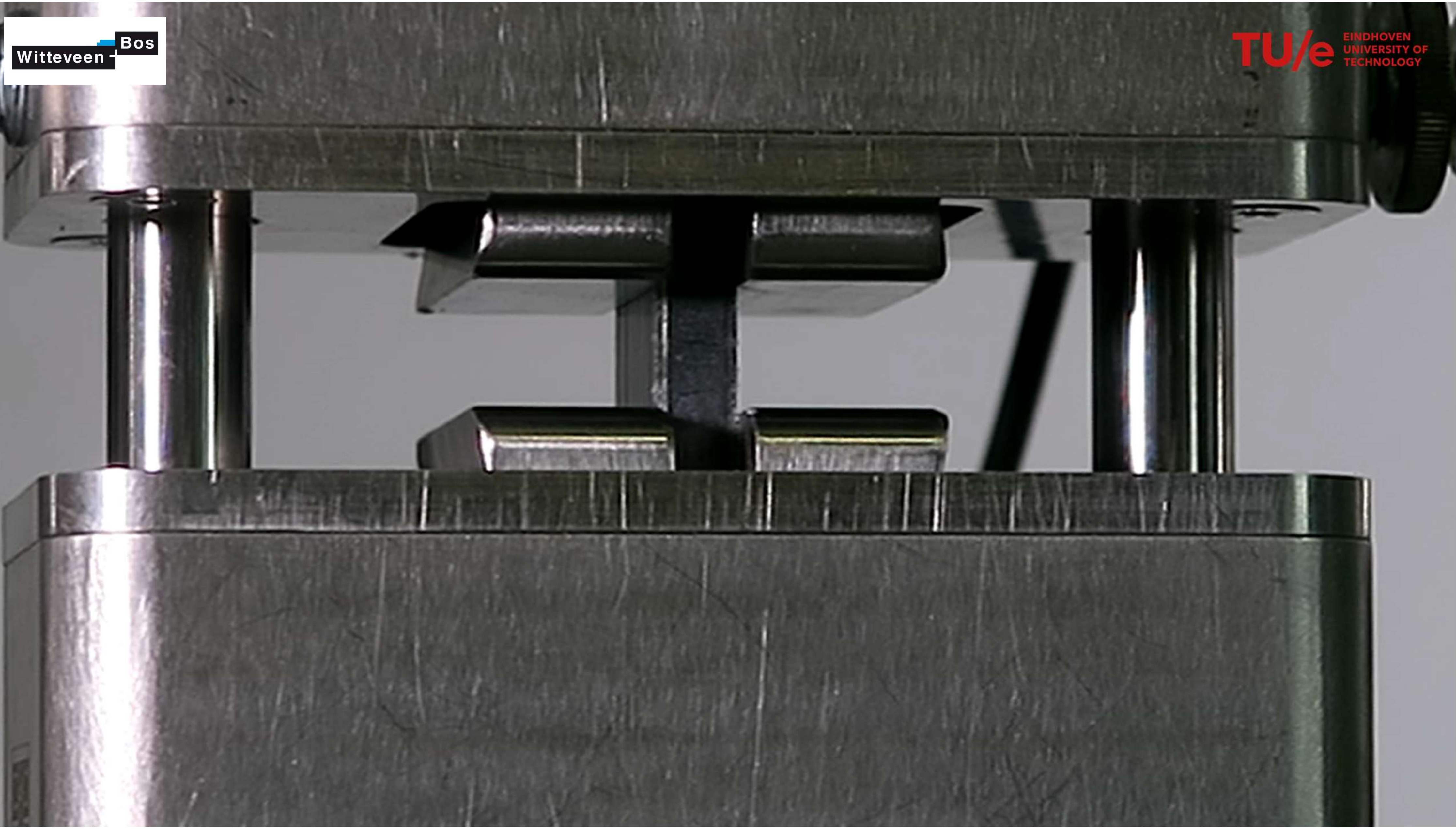



Witteveen + Bos
ASTM D3410 TESTING FIXTURE
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY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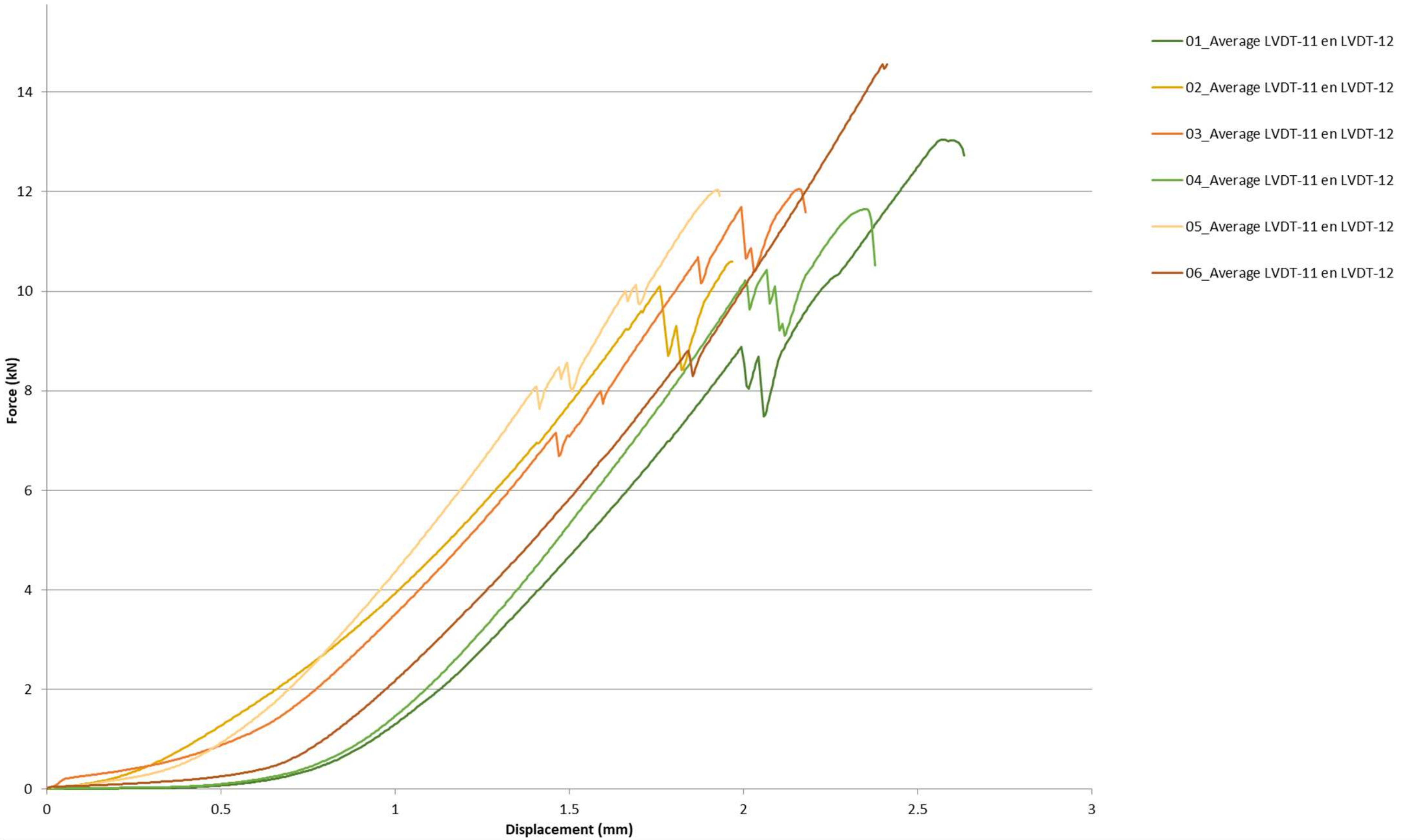
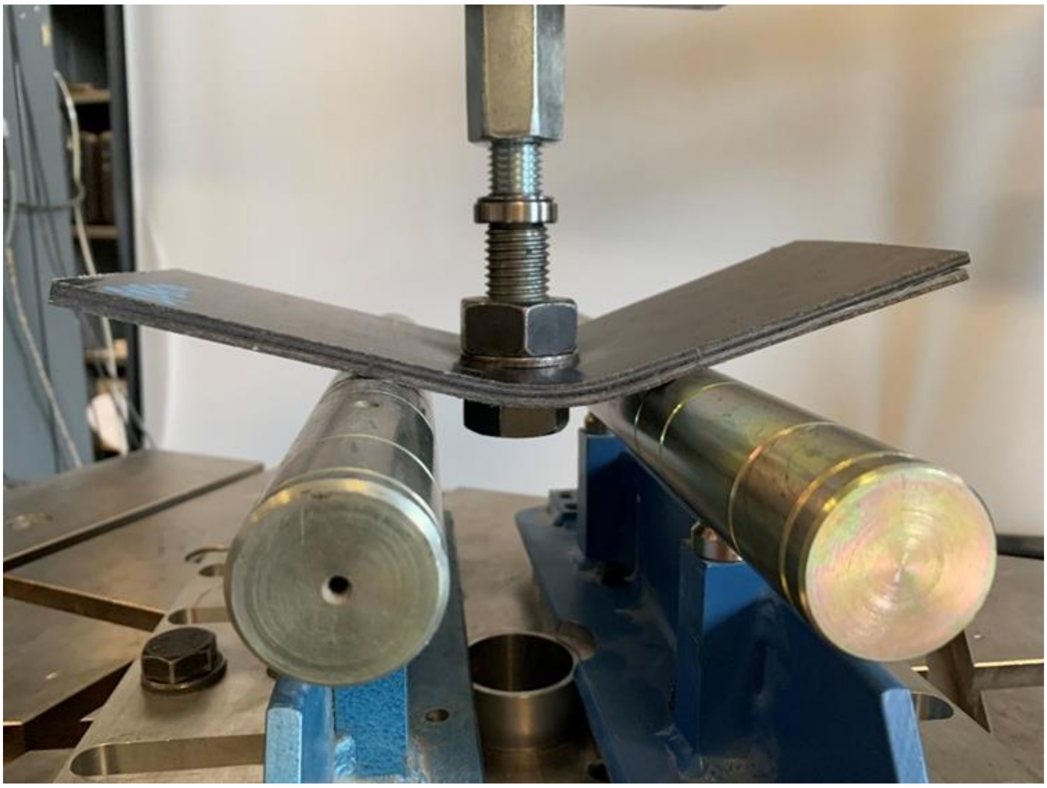
Force-Displacement all in one Compression transverse



5.5 Appendix E – Report 3-point bending punching shear

3-point bending punching shear composite sheet piles

ASTM D7264/D7264M – 21



Project name: Opwaardering Twentekanalen
Client: Rijkswaterstaat GPO
Contractor: Combinatie Van Oord, Hakkers, Beens
Sub contractor: Witteveen+Bos, TU/e, Dept. of Built Environment

Status: Final
Revision: 1.0 – 17-03-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0	Prepared by			
	Checked by			
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0		Final Version

Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date tested:	17-03-2023
Test standards:	ASTM D7264/D7264M - 21
Material:	E-glass, polyester
Specimen type:	-
Pre-treatment:	21 °C / 45-50% RV
Machine:	Instron 5985
Pre-load:	0 MPa
Test speed:	1 mm/min
C.t.c. distance supports:	100 mm (M24) / 120 mm (M30)
Bolts:	M24 / M30
Ring diameter:	120 mm

Table of content

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

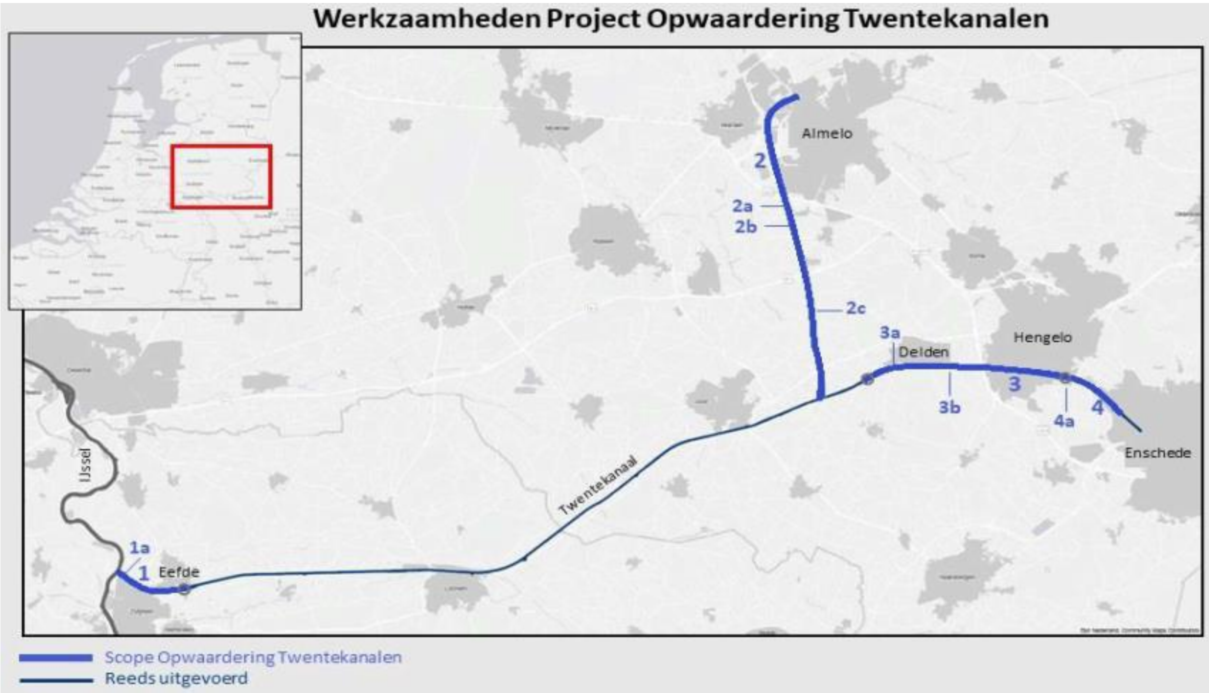


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometre points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **punching shear tests** conducted on the composite sheet piles.

2 Test and material

This paper will present the results obtained from 3-point bending punching tests conducted on composite sheet piles that were cut in the longitudinal direction. The testing method adheres to the guidelines outlined in ASTM D7264/D7264M – 21, while the test setup and dimensions are based on CUR96. The objective of this test was to predict real-world behaviour, which is why it deviates from the ASTM test setup. The material is exclusively tested along the fibre direction, i.e., the longitudinal direction. Due to the limited flat length in the transverse direction of the composite sheet pile, it is not possible to conduct testing in that direction as well.

These sheet piles are constructed from pultruded glass fibre polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in³/ft	703.22	cm³/m
Moment of Inertia	54.01	in⁴/ft	7375.52	cm⁴/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in²	47.94	cm²
Standard Color	Graphite Gray			

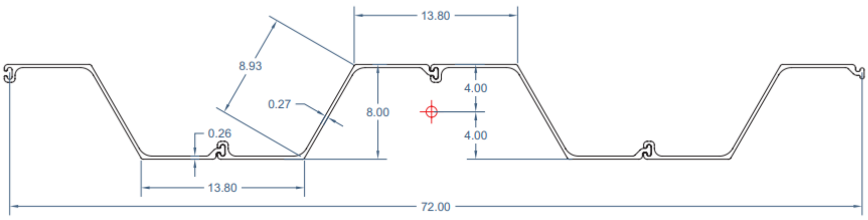
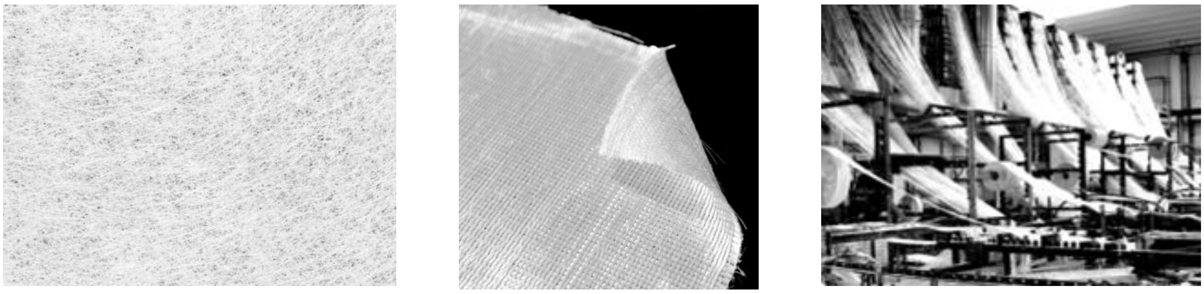


Figure 2-1 Superloc Series 1580

The glass fibre volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibres on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament | 0/90 Fabric | 0 Direction

Figure 2-2 Visual representation glass fibres used

3 Preparation and equipment used

The dimensions of the specimens were taken from ASTM D7264/D7264M - 21, as detailed in Table 3-1. Appendix A includes the sawing plan for the samples extracted from the sheet pile elements. In this test, only the samples labelled as 'DPBxx' are relevant. Initially, the sample length was determined based on the ASTM standard, which specified 32 times the thickness (6.7mm) for the distance between supporting points. An additional 30mm was added on both sides to prevent the sample from slipping off the supports. The specimens were prepared using waterjet cutting at the Equipment and Prototype Centre of the Technical University in Eindhoven. Figure 8-1, 8-2, and 8-3 in Appendix A indicate where the samples were obtained from the sheet pile. No specific consolidation methods were employed afterward, and the samples were stored in the test lab. No non-destructive testing methods were conducted prior to this test.

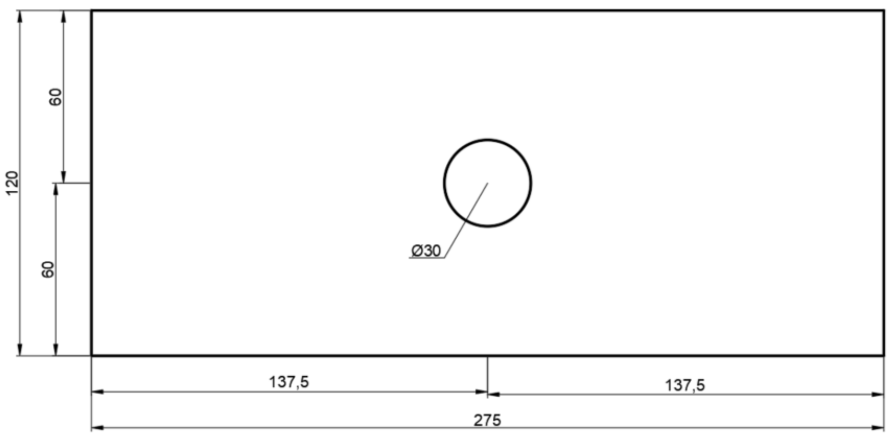
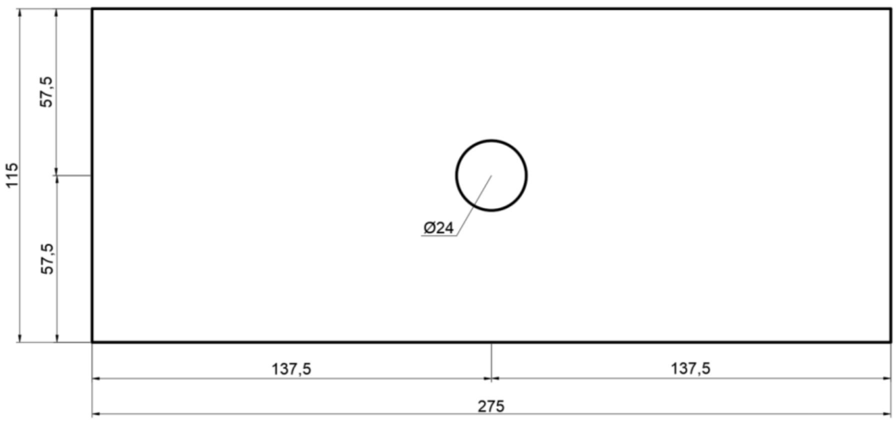
DPB01 DPB02 DPB03	
DPB04 DPB05 DPB06	

Table 3-1: Sample dimensions

For this test, an Instron 5985 machine manufactured on May 15, 2014, with a capacity of 250kN was utilized. The machine underwent its most recent calibration on February 14, 2022, by NMI Certin. Data was directly collected from the Instron machine using Bluehill Universal computer software to measure the material strain. The data was then exported as CSV files, which were subsequently imported into Excel for data processing.

To measure the average cross-section of the samples, a digital caliper was utilized, capable of measuring up to 1/100th of a millimetre. Unfortunately, the calibration date for the caliper is unknown.

The raw data consisted of Time, Force, and Flexure displacement. Input data for the computer software included Length, Thickness, and Width. Width and thickness were measured at three points for each sample gauge length, and the results can be found in Table 3-2.

3-point bending punching shear									
	Edge	Middle	Edge		Edge	Middle	Eedge		
Sample	Width (mm)	Width (mm)	Width (mm)	**Average width (mm)**	Thickness (mm)	Thickness (mm)	Thickness (mm)	**Average thickness (mm)**	**Average area (mm2)**
DPB01	120,18	120,13	119,9	120,07	6,87	6,72	6,85	6,81	806,87
DPB02	120,23	120,2	120,28	120,24	6,85	6,76	6,76	6,79	812,8
DPB03	120,16	120,11	120,11	120,13	6,7	6,75	6,74	6,73	810,86
DPB04				115*				6,7*	770,5*
DPB05	115,4	115,39	115,27	115,35	6,81	6,75	6,77	6,78	778,64
DPB06	115,56	115,45	115,37	115,46	6,75	6,81	6,73	6,76	786,28

**DPB04 is not measured, therefore it includes theoretical values*

Table 3-2: Dimensions test samples

Both types of specimen dimensions underwent 3-point bending punching shear tests in the longitudinal direction of the material. Figure 3-1 depicts the test setup for both tests. It's important to note that the support points are positioned at a distance of 2 times the diameter away from the centre of the bolt, following the CUR96 guidelines for minimum edge distances. This also clarifies the width of the samples, which is 2 times the diameter on both sides. In contrast, ASTM recommends a minimum support distance of 32 times the thickness, which would equate to 215mm in this case. However, as mentioned in the introduction, the aim was to predict the actual behaviour of the material. Using a 215mm support point distance would significantly increase the likelihood of the sample failing due to bending. The test setup employed here provided a higher probability of failure due to punching shear of the bolt, which was the desired outcome. Figure 3-2 illustrates the test setup during the test execution.

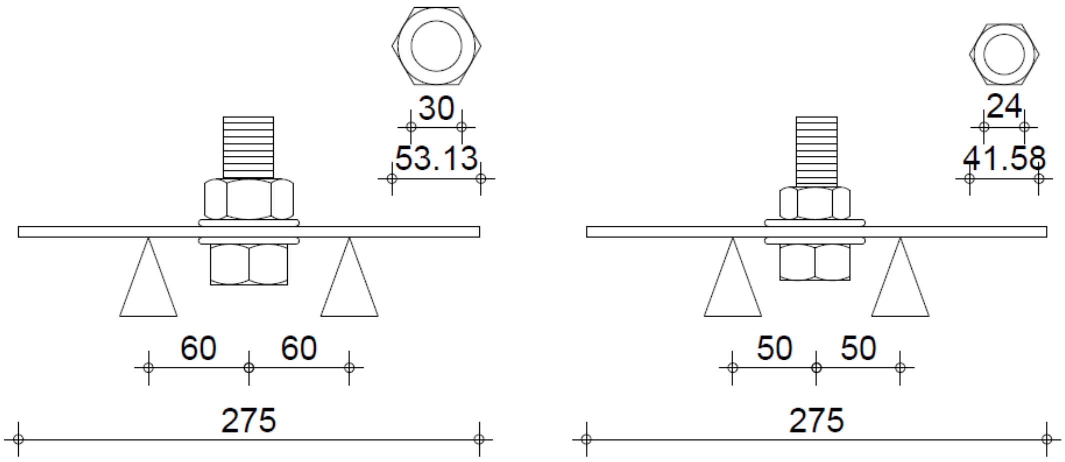


Figure 3-1 Test setup during the test

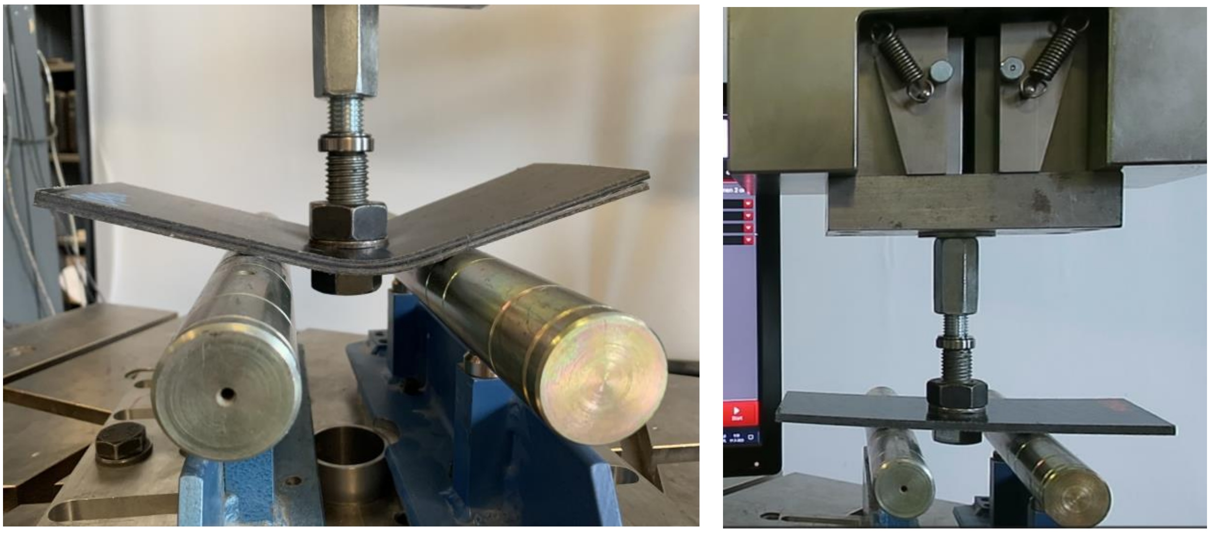


Figure 3-2 Test setup during the test

Figure 3-3 and 3-4 depict the preparations of the test setup and alignment methods. This approach guaranteed the most precise alignment of the test setup that we could achieve using the tools at our disposal.


Figure 3-3 Preparations test setup

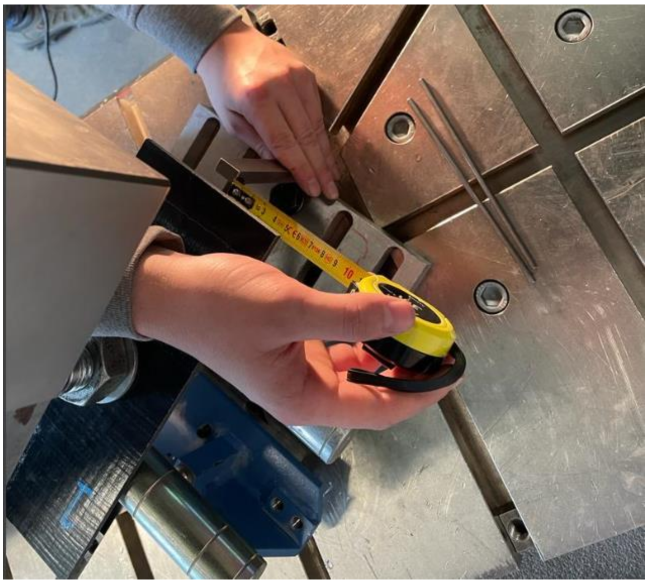


Figure 3-4 Preparations test setup

Cylinder-Supported Punching Shear Test

During the tests, it was realized that there were remaining samples that could be adapted for a punching shear test supported by a cylinder. These samples were manually cut to approximate dimensions of 115x115 mm, with an M24 bolt. The setup for this ring test is illustrated in Figure 3-5. The ring configuration increases the likelihood of punching shear failure even further. However, it's important to note that this test does not simulate the normal conditions of the sheet pile. It was not prepared according to any scientific method or mounting instructions, such as CUR96. The test was carried out solely to induce the sample to fail in punching shear under the most extreme conditions possible.

Figure 3-5 Preparations test setup

4 Results

Figure 4-1 displays the Force-Displacement graphs for all the tested samples. Figure 4-2 includes only the graphs for the 24mm bolts, Figure 4-3 includes only the 30mm bolts, and Figure 4-4 comprises the tests conducted on the cylinder.

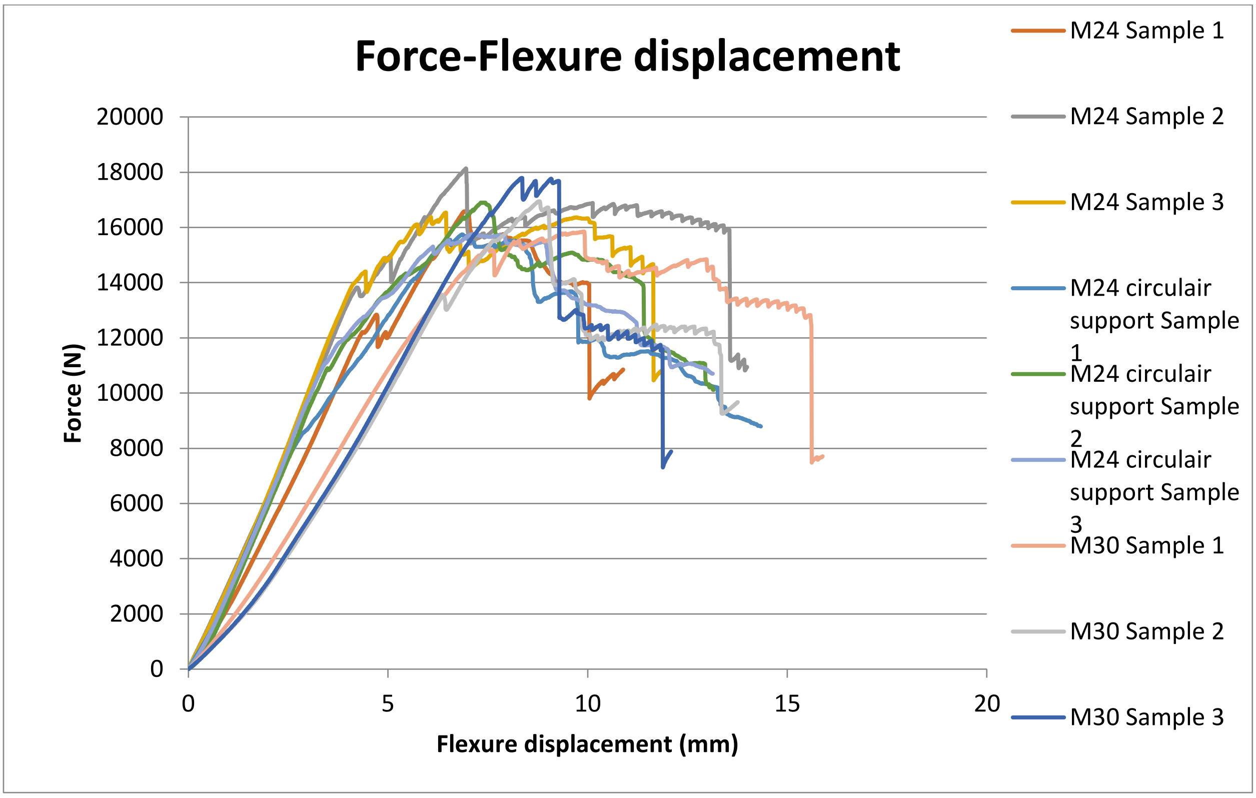


Figure 4-1 Force flexure displacement all tested samples

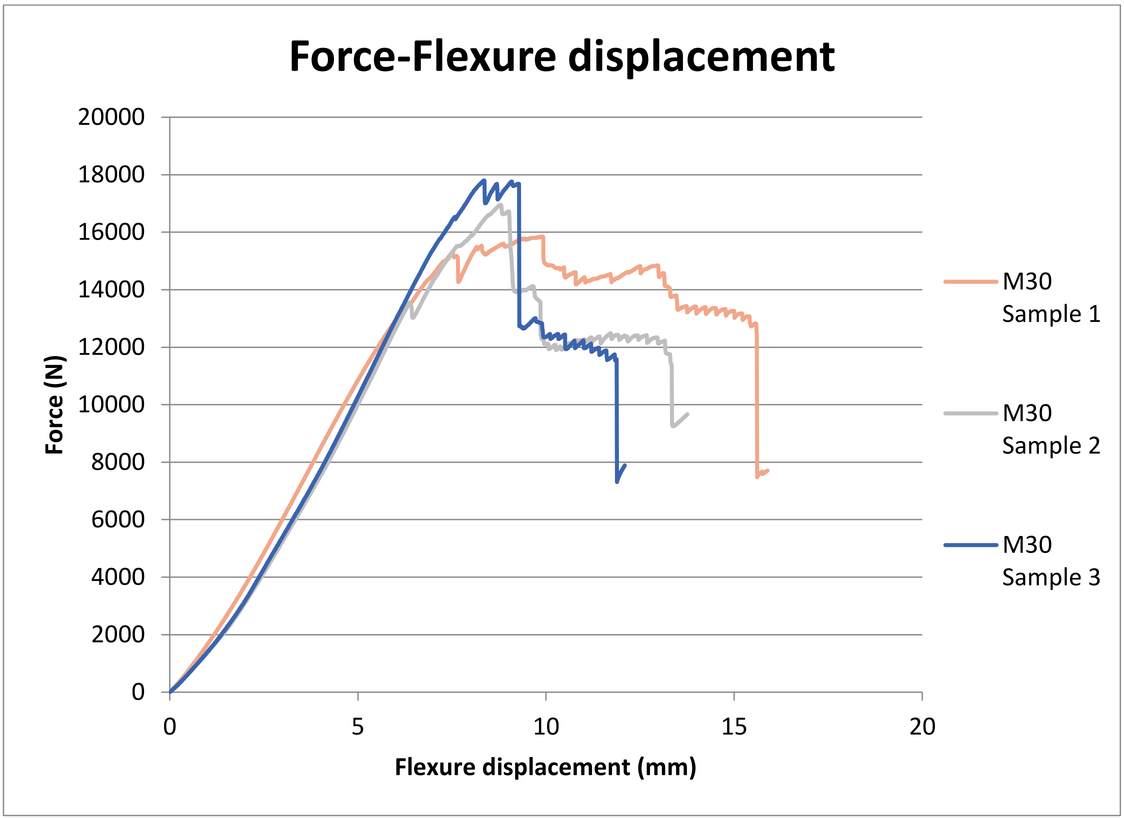


Figure 4-2 Force flexure displacement M30 samples

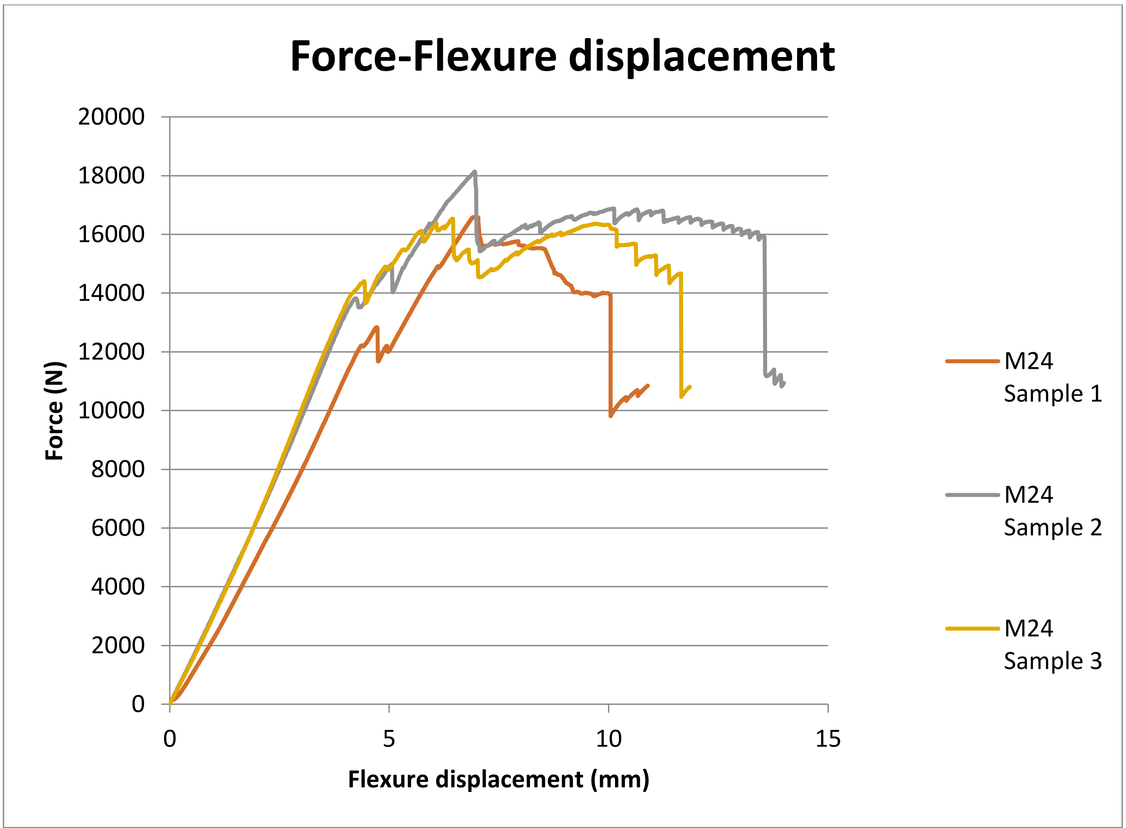


Figure 4-3 Force flexure displacement M24 samples

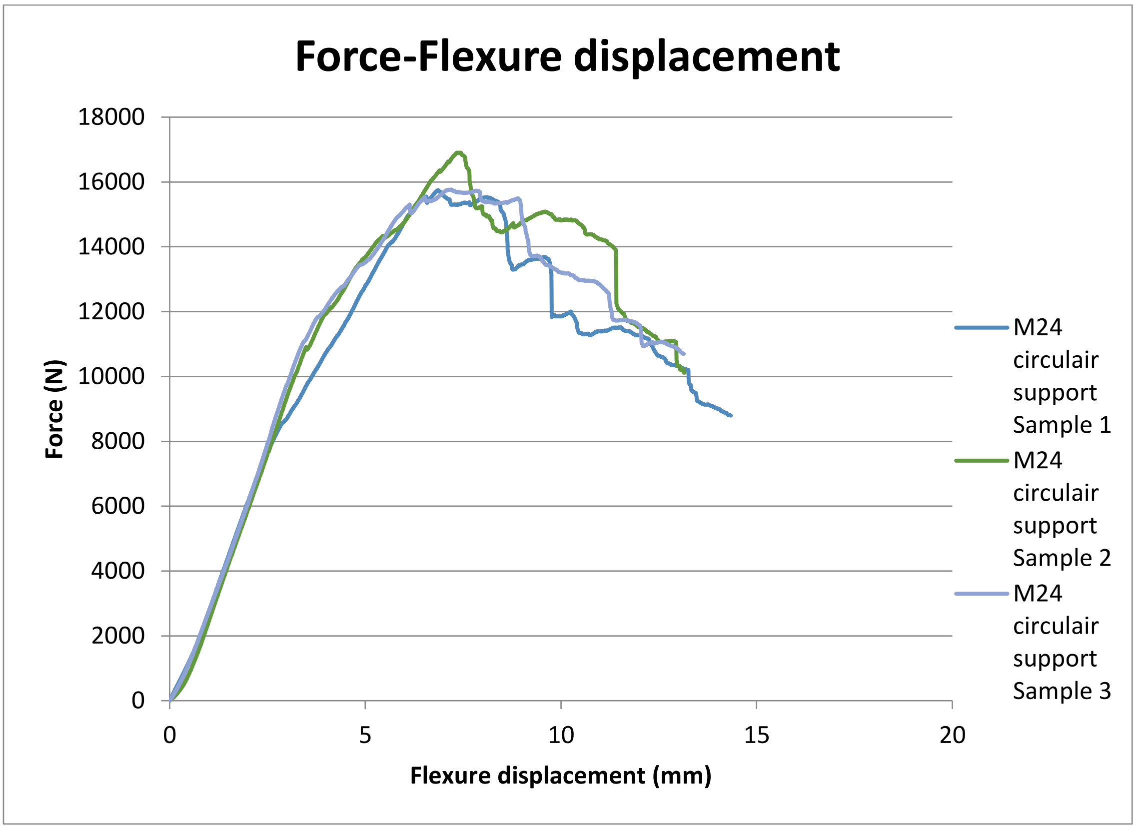


Figure 4-4 Force-flexure displacement circular support

4.1 Additional Calculations

The sample failures revealed that none of the bending tests actually resulted in punching shear failure. The initial point of failure indicates compression buckling or local failure of the top layer (Figure 4-5). Complete failure occurs due to interlaminar shear (Figure 4-6).

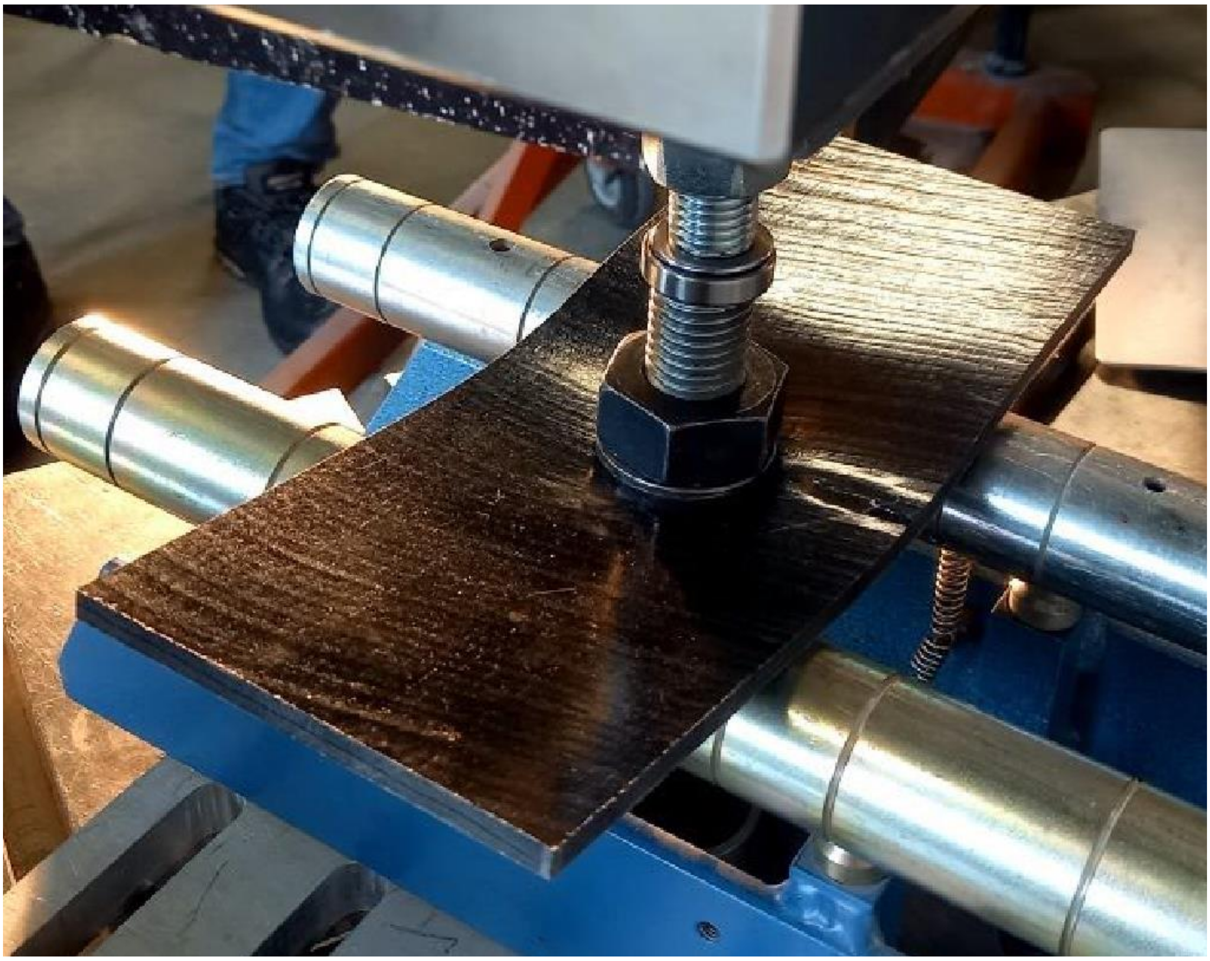


Figure 4-5 First local failure

Figure 4-6 Complete failure (interlaminar shear)

5 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value

n = number of tests

V_x = Which is the coefficient of variation $V_x = S_x/m_x$

S_x = Standard deviation

m_x = average value

k_n = Static factor which can be calculated with $k_n = K* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.

K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 5-1: k_n values

6 Bearing responds

6.1 Maximum bending stress

Table 6-1 and 6-2 display the bending stress data for the M24 bolt samples in the 3-point bending test. The "1st failure stress" is determined as the point where the linear line in the force vs. displacement graphs is initially interrupted. The "max failure stress" is identified as the point where the highest force is reached during the test. Further explanations of the failures occurring at these points can be found in the "Section Failure Mode."

M24 1st failure stress		
Sample	Stress (Mpa)	Deviation (MPa)
DPB04	370,79	370,790
DPB05	391,41	391,409
DPB06	409,12	409,121
Average (MPa)	390,440	
Standard deviation (MPa)	15,663	
Coefficient of variation (%)	4,01	
K	1,645	
kn	1,899	
n	3	
Rk (MPa)	360,688	

Table 6-1: *1st* Failure stress M24 (1)

M24 max. failure stress		
Sample	Stress (Mpa)	Deviation (MPa)
DPB04	481,87	481,874
DPB05	513,65	513,649
DPB06	469,59	469,587
Average (MPa)	488,370	
Standard deviation (MPa)	18,565	
Coefficient of variation (%)	3,80	
K	1,645	
kn	1,899	
n	3	
Rk (MPa)	453,105	

Table 6-2: *1st* Failure stress M24 (2)

Table 6-3 and 6-4 provide the bending stress data for the M24 bolt samples in the 3-point bending test. The "1st failure stress" is defined as the point where the linear line in the force vs. displacement graphs is first disrupted. The "max failure stress" is established as the point at which the highest force is recorded during the test. Additional details regarding the failures occurring at these points are presented in the "Section Failure Mode."

M30 1st failure stress		
Sample	Stress (Mpa)	Deviation (MPa)
DPB01	489,99	489,993
DPB02	458,69	458,686
DPB03	588,84	588,842
Average (MPa)	512,507	
Standard deviation (MPa)	55,469	
Coefficient of variation (%)	10,82	
K	1,645	
kn	1,899	
n	3	
Rk (MPa)	407,144	

Table 6-3: *1st* Failure stress M30 (1)

M30 max. failure stress		
Sample	Stress (Mpa)	Deviation (MPa)
DPB01	511,95	511,953
DPB02	550,384	550,384
DPB03	588,84	588,842
Average (MPa)	550,393	
Standard deviation (MPa)	31,390	
Coefficient of variation (%)	5,70	
K	1,645	
kn	1,899	
n	3	
Rk (MPa)	490,769	

Table 6-4: *1st* Failure stress M30 (2)

The formula used for deciding the stress is:

$$\sigma = (3*P*L)/(2*b*h^2)$$

Where:

σ = stress at the outer surface at mid-span (MPa)
P = applied force (N)
L = support span (mm)
b = width of beam (mm)
h = thickness of beam (mm)

Based on the formula, considering equal width, thickness, and applied force, the stress on the M30 is expected to be approximately 20% higher compared to the M24 because the support span has increased by 20% (from 100mm to 120mm). However, the results indicate that the increase from M24 to M30 is actually less than 20%.

6.2 Failure mode

In the bending test, a three-step failure process is evident, as seen in the force vs. displacement graphs. It's noticeable that there's a point where the linear portion of the line is interrupted; this marks the occurrence of the first failure. Typically, this is represented by a crack that runs across the width of the sample, leading to local buckling of the top layer at the location of the bolt. Subsequently, the force vs. displacement graphs show that the force increases to a maximum point. This is where the crack starts to propagate towards either of the edges, as shown in Figure 6-1. It's important to note that the crack hasn't yet spread across the entire width at this stage. Finally, the force abruptly drops, indicating that the crack at the edge has extended across the full width of the sample, as visible in Figure 6-2. The corresponding code for this failure mode is "IAM," which stands for interlaminar shear at the loading nose in the middle, ultimately extending to the edges and covering the entire width.

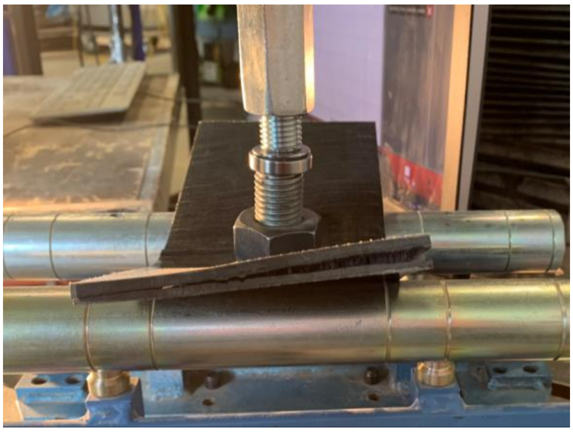


Figure 6-1 Fail with crack to right edge (1)


Figure 6-2 Fail with crack to right edge (2)

For the punching shear test using the support cylinder, the failure mechanism is more or less identical. Figures 6-1 and 6-2 clearly show delamination that starts locally next to the washer. When examining the samples from below, as shown in Figures 6-3 and 6-4, it is apparent that the washer almost pierced through the material. However, due to the severe delamination of the material, as evident in Figures 6-3 and 6-4, the material couldn't withstand enough force for the washer to completely penetrate it. Furthermore, the material returns to its original state when the pressure is removed, as depicted in Figures 6-5 and 6-6.

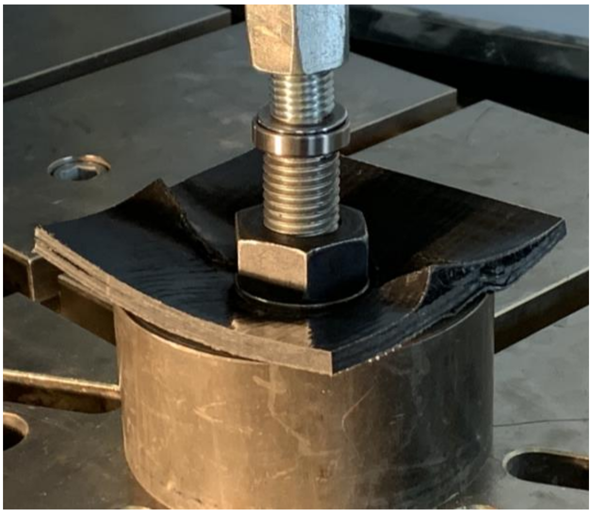


Figure 6-3 Bad delamination due to support cylinder (1)

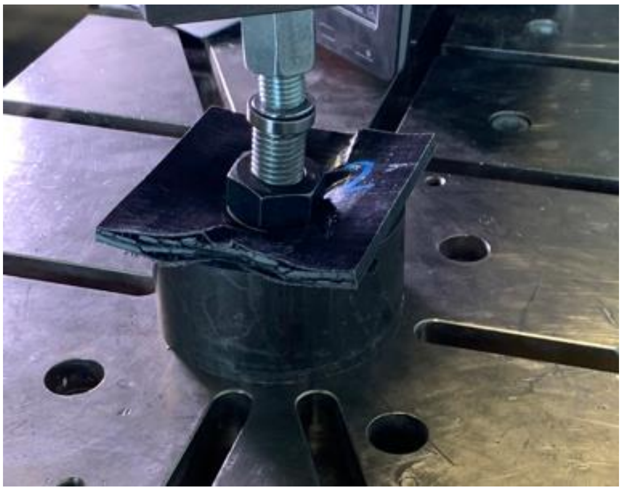


Figure 6-4 Bad delamination due to support cylinder (2)

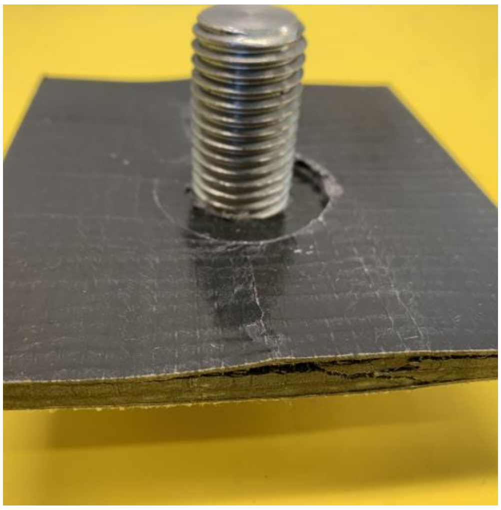


Figure 6-5 Specimen to original state (1)

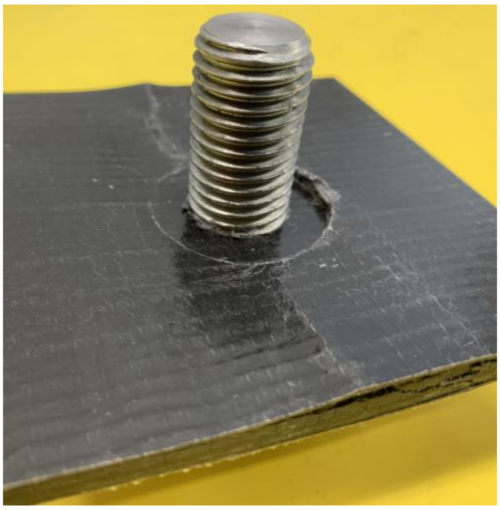


Figure 6-6 Specimen to original state (2)

Theoretical maximum bending strength

With the observed failure mechanism, the maximum bending strength can be calculated with the following formula from the CUR96:

$$F_{zt,l,Rd} = \frac{\tau_{z,Rd}\,\pi\,d_r\,t}{k_{sc1}}$$

Where:

$\tau_{z,Rd}$ is the lowest design value for the interlaminar shear strength of the laminate in the x-z or y-z plane, $\tau_{xz,Rd}$ and $\tau_{yz,Rd}$;

d_r is the external diameter of the washer;

k_{sc1} is the reduction factor, derived from tests. k_{sc1} = 2.0 applies as a conservative indicative value.

The results can be observed in Tables 6-5 and 6-6. For both the M30 and M24 tests, the same washer was employed, so there should be no disparity in strength. These results provide an approximation of the outcomes obtained from the test.

Bolt	M	=	**24**	mm
Bolt hole	d	=	**24**	mm
Thickness sample	t	=	**6,7**	mm
Diameter washer	d_r	=	**44**	mm
Strength	τ_m	=	**26,1**	MPa
	γ_m	=	**1,0**	
	η_{ck}	=	**1,0**	
Reduction factor	k_{sc1}	=	**2,0**	Conform CUR96
Design bore hole strenght column	$\tau_{z,Rd}$	=	**26**	MPa
	$F_{z,t,l,Rd}$	=	**12,1**	kN

Table 6-5: M24 maximum strength

Bolt	M	=	**30**	mm
Bolt hole	d	=	**30**	mm
Thickness sample	t	=	**6,7**	mm
Diameter washer	d_r	=	**44**	mm
Strength	τ_m	=	**26,1**	MPa
	γ_m	=	**1,0**	
	η_{ck}	=	**1,0**	
Reduction factor	k_{sc1}	=	**2,0**	Conform CUR96
Design bore hole strenght column	$\tau_{z,Rd}$	=	**26**	MPa
	$F_{z,t,l,Rd}$	=	**12,1**	kN

Table 6-6: M30 maximum strength

The outcome is the same because the outer diameter of the washer is the same.

7 Summary

Summarizing the results from the punching shear tests, the following outcomes are obtained and presented in Table 7-1.

Results punching strength	
Characteristic 1st punching failure strength M24 - 44 mm washer	12.4 kN
Characteristic 1st punching failure stress M24- 44 mm washer	361 MPa
Characteristic punching failure strength M24- 44 mm washer	15.7 kN
Characteristic punching failure stress M24- 44 mm washer	453 MPa
Theoretical maximum punching failure strength M24 - 44 mm washer	12.1 kN
Characteristic 1st punching failure strength M30- 44 mm washer	12.8 kN
Characteristic 1st punching failure stress M30- 44 mm washer	407 MPa
Characteristic punching failure strength M30- 44 mm washer	15.4 kN
Characteristic punching failure stress M30- 44 mm washer	491 MPa
Theoretical maximum punching failure strength M30 - 44 mm washer	12.1 kN

Table 7-1: Characteristic punching shear properties, retrieved from the tests

8 Appendix

8.1 Appendix A – Sample numbering

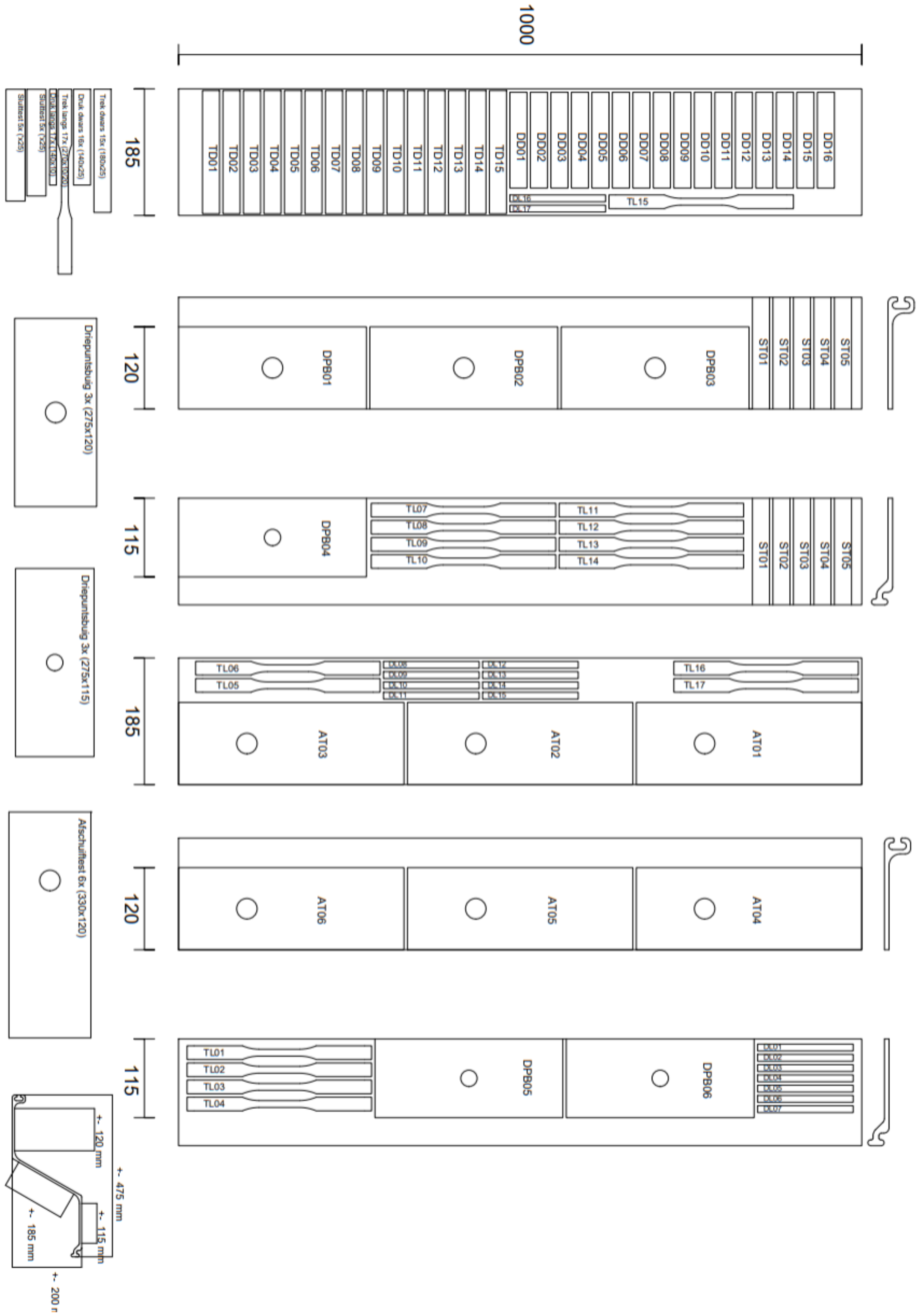


Figure 8-1 Saw plan all samples

Figure 8-2 Samples retrieved from sheet

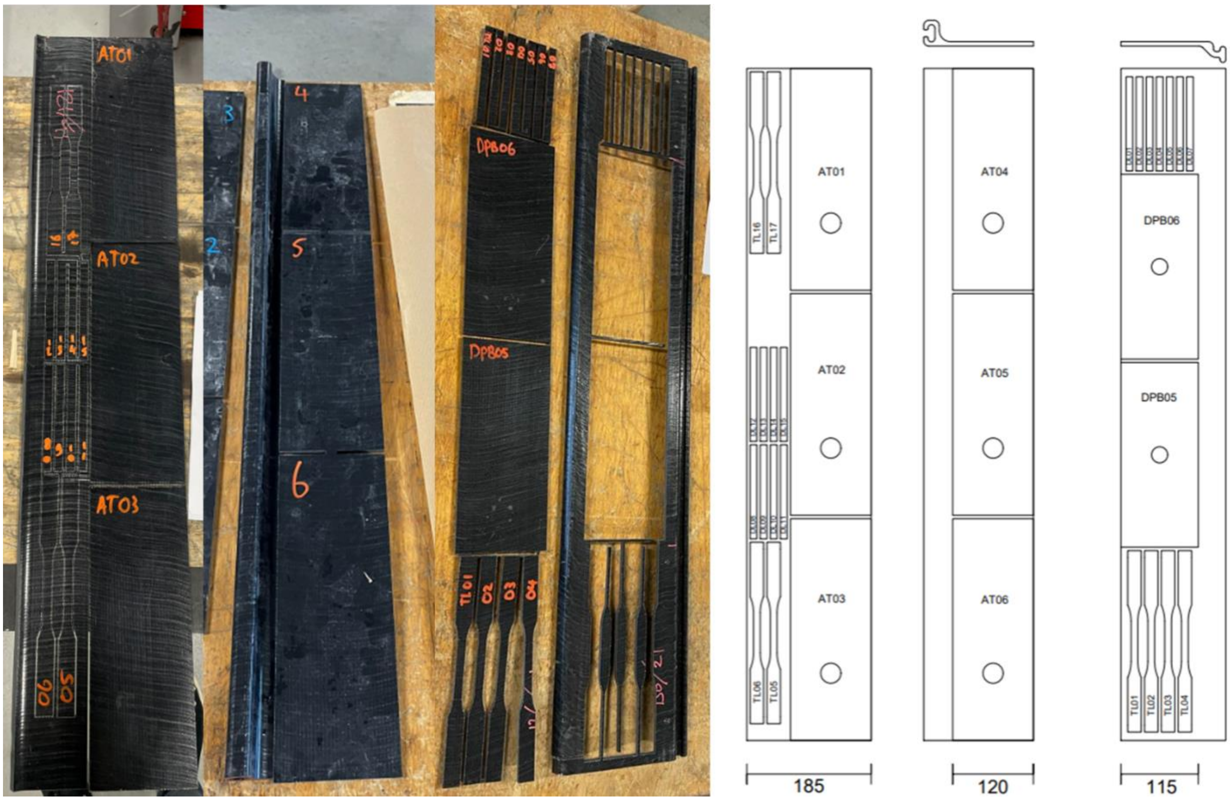
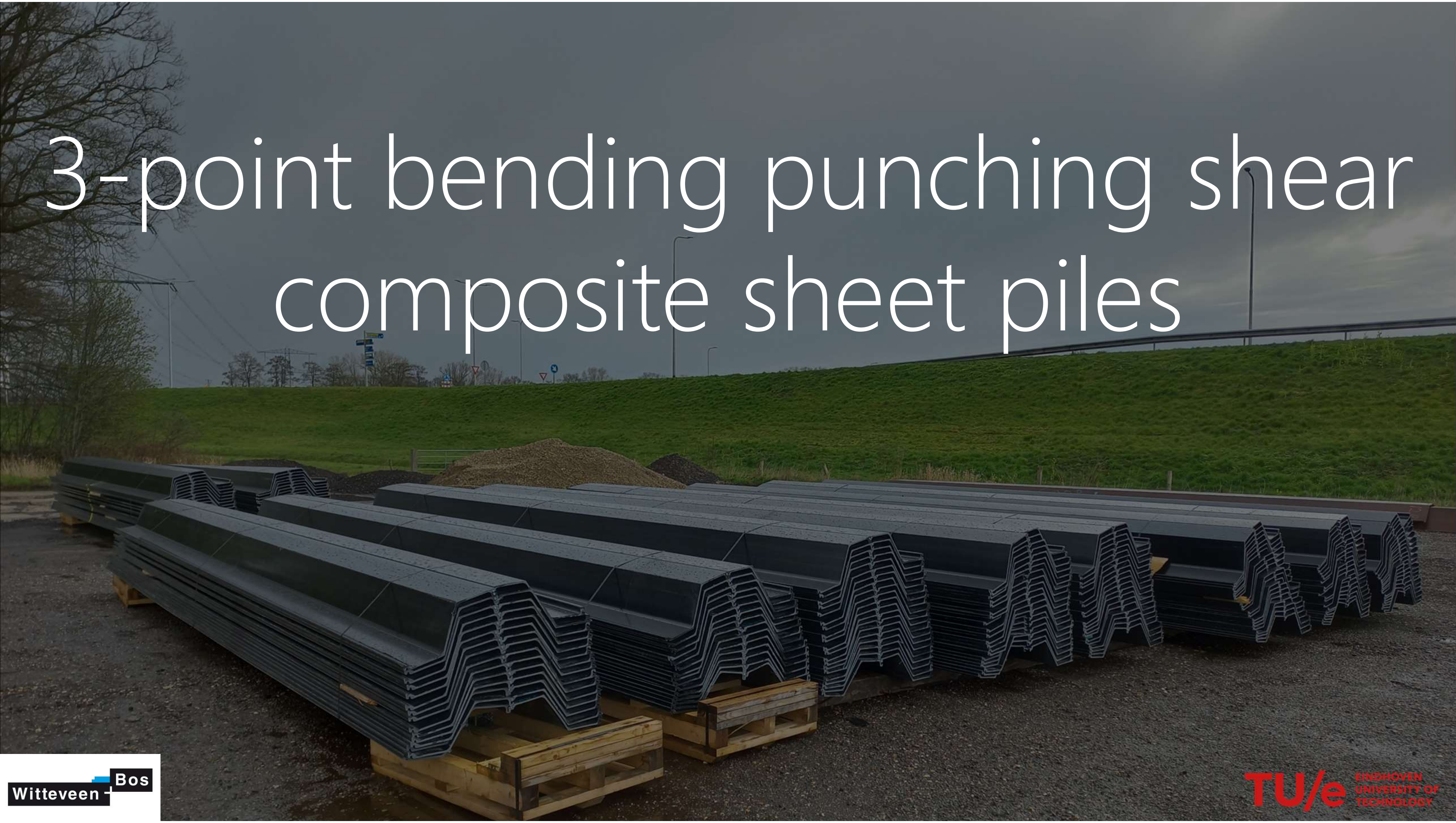


Figure 8-3 Samples retrieved from sheet

8.2 Appendix B – Presentation results and test

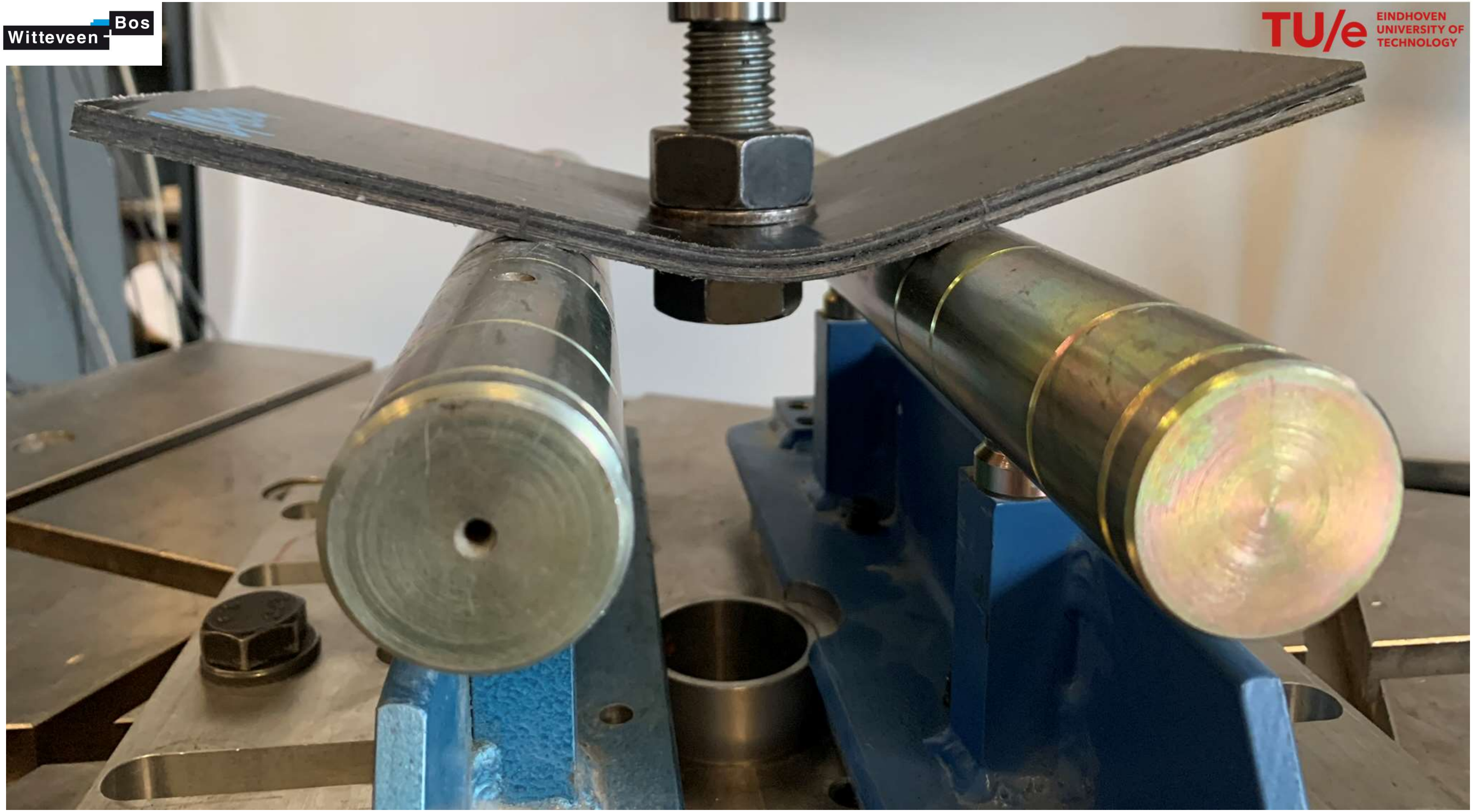
3-point bending punching shear composite sheet piles

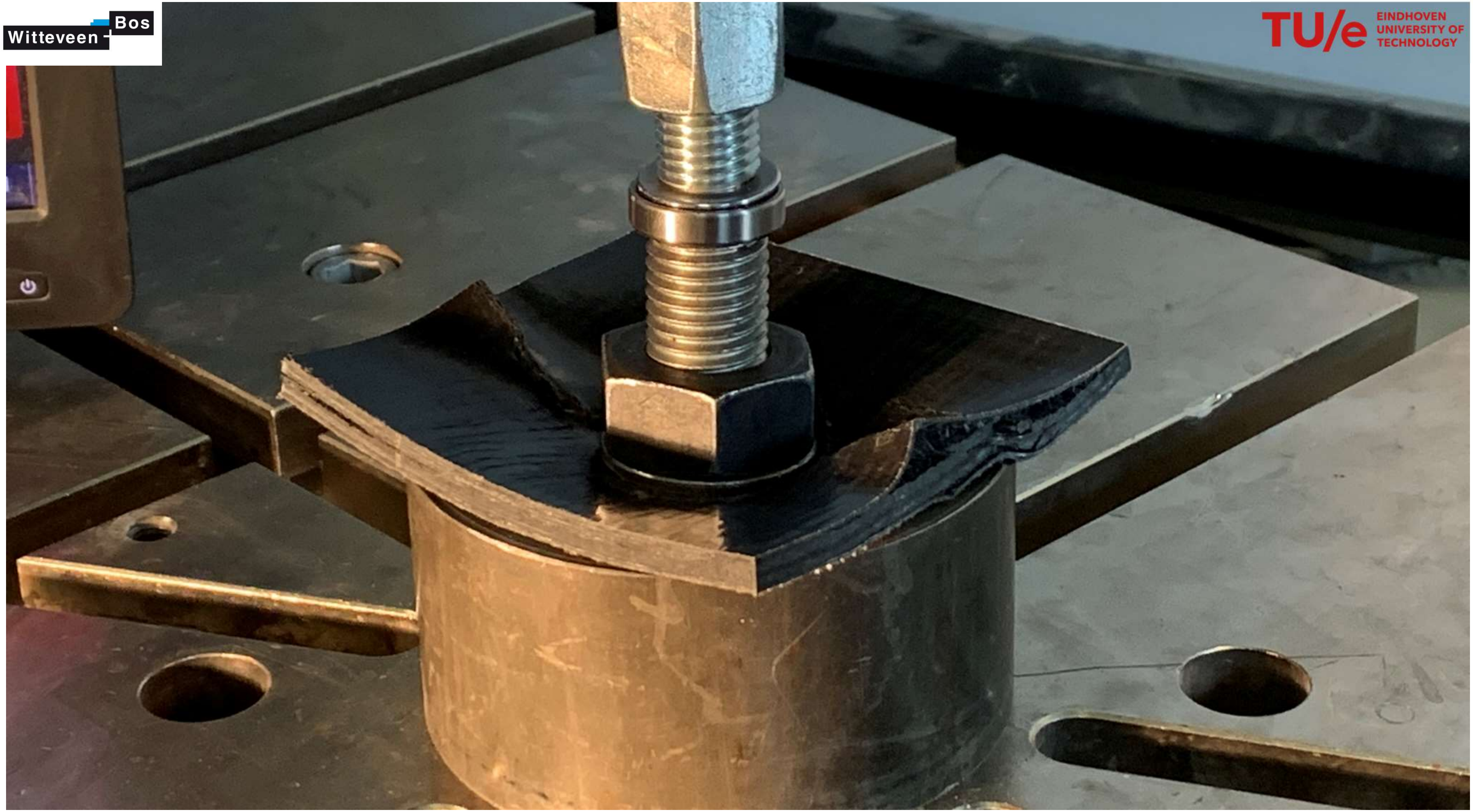


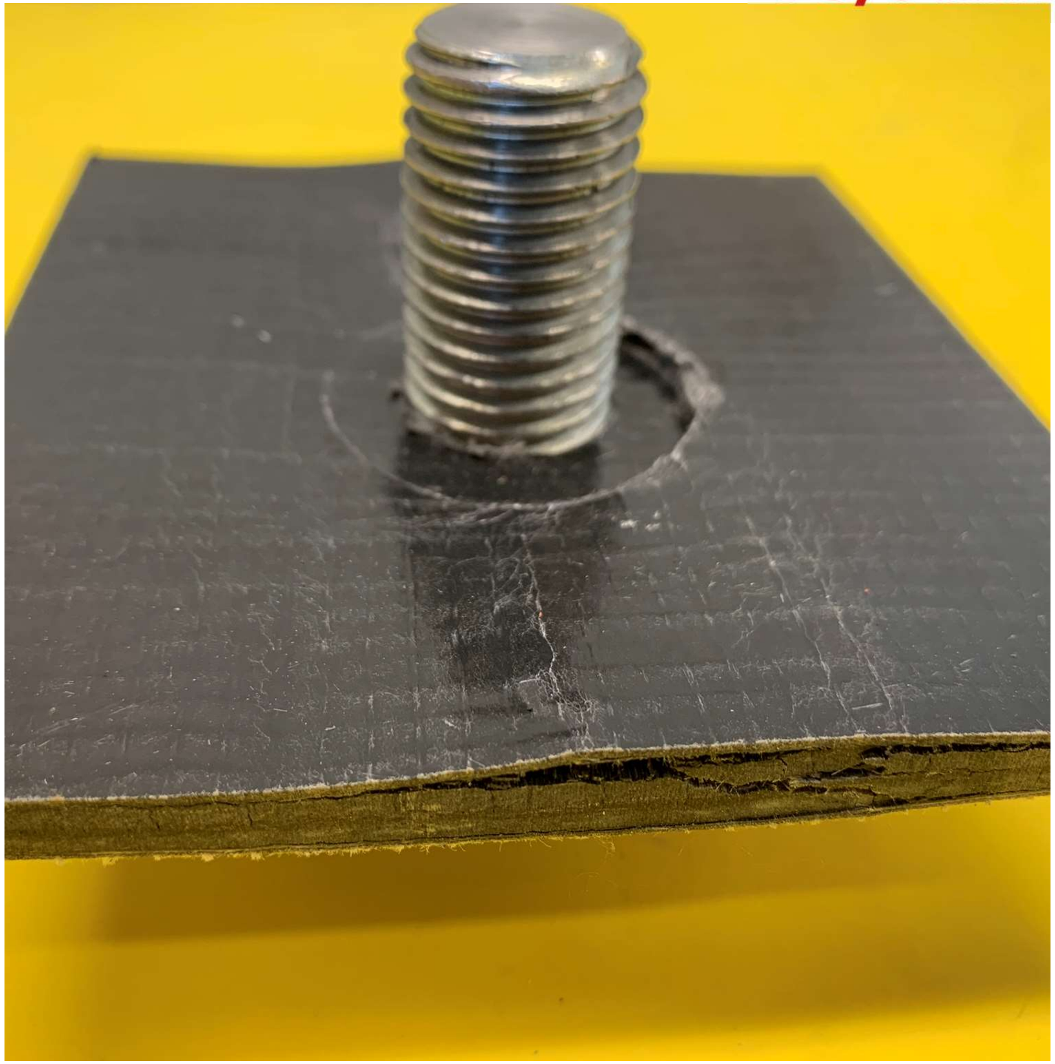
Witteveen+Bos

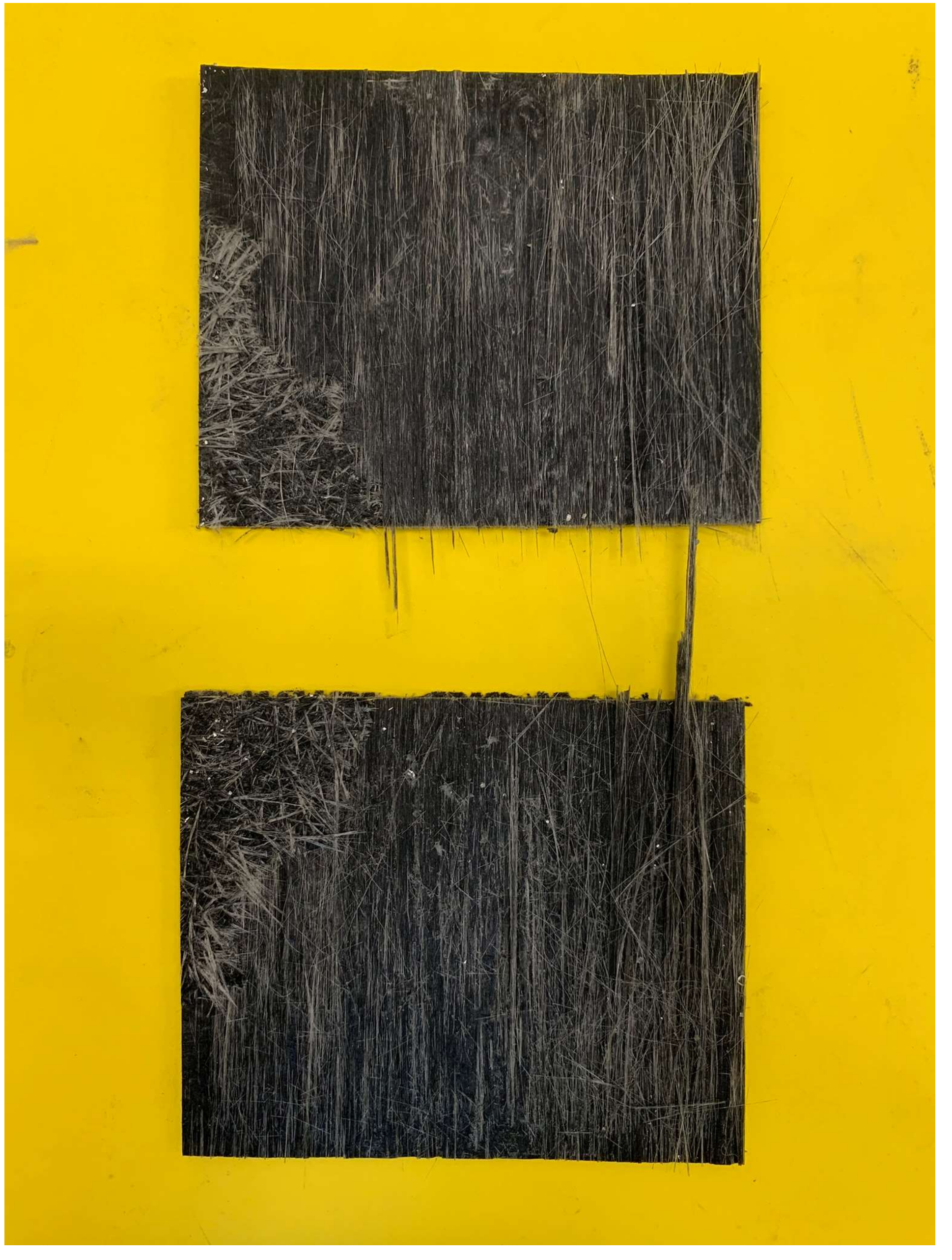
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

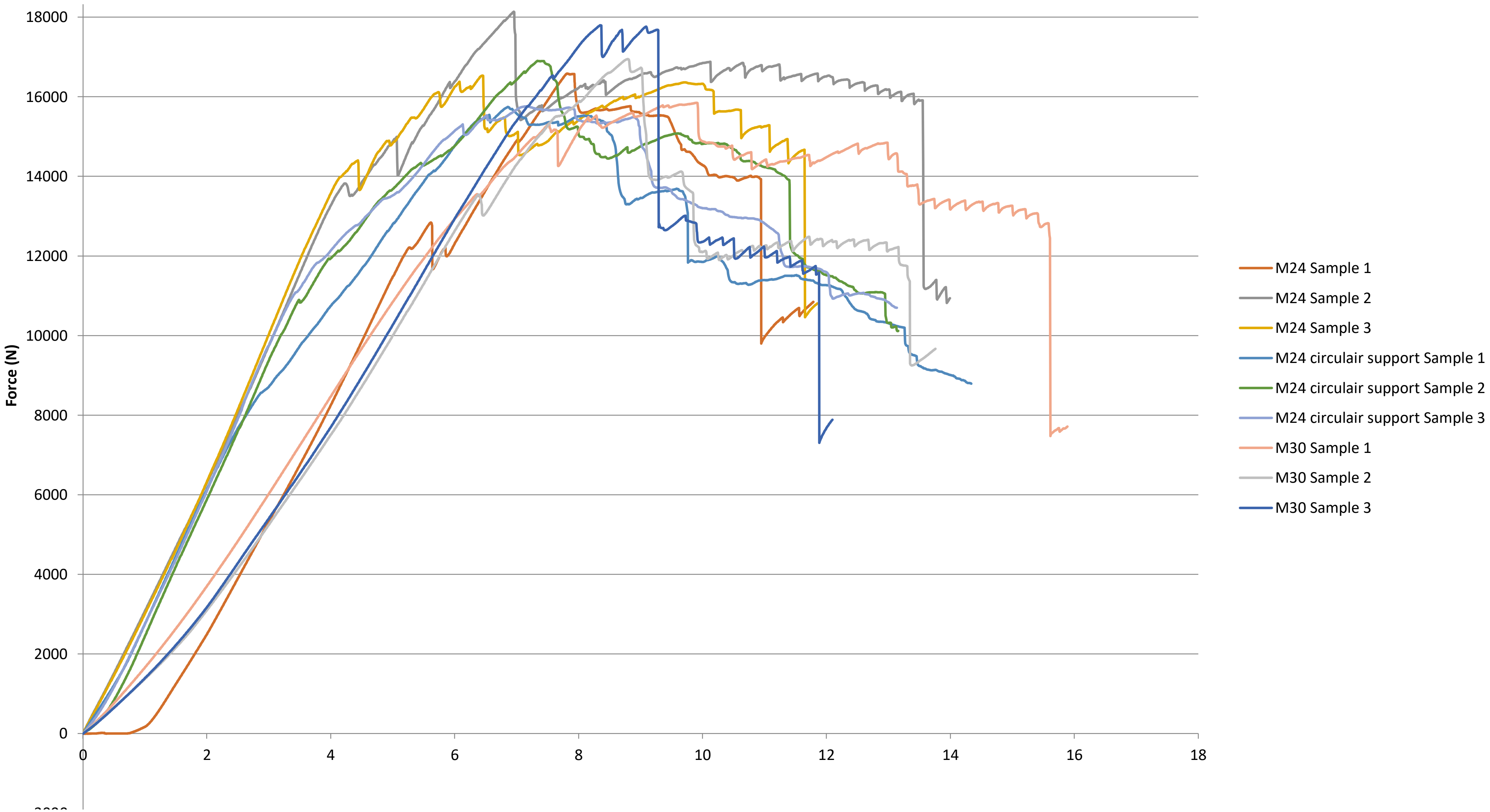

Witteveen+Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Bluehill Universal
Time [s]
59.310
Force [N]
6.2E+003
Displacement [mm]
3.6085
Test
Method
Report
Graph 1
3 point flex bio-based Ulm 1 to 2
Graph 2
3 point flex bio-based Ulm 2
Operator inputs
Displacement [mm]
Force [N]
Stop
1 Balance Force
2 Balance all
3 Zero Displacement
4 Return
Type here to search
hp


Witteveen Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY







Force (N)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
16
18
M24 Sample 1
M24 Sample 2
M24 Sample 3
M24 circulair support Sample 1
M24 circulair support Sample 2
M24 circulair support Sample 3
M30 Sample 1
M30 Sample 2
M30 Sample 3

5.6 Appendix F – Report Tensile lock test

Tensile lock test composite sheet piles

-

Project name: Opwaardering Twentekanalen
Client: Rijkswaterstaat GPO
Contractor: Combinatie Van Oord, Hakkers, Beens
Sub contractor: Witteveen+Bos, TU/e, Dept. of Built Environment

Status: Final
Revision: 1.0 – 08-03-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0	Prepared by			
	Checked by			
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0		Final Version

Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date tested:	08-03-2023
Test standards:	-
Material:	E-glass, polyester
Specimen type:	male & female lock
Pre-treatment:	21 °C / 45-50% RV
Machine:	Instron 5985
Pre-load:	0 MPa
Test speed:	2 mm/min

Table of content

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

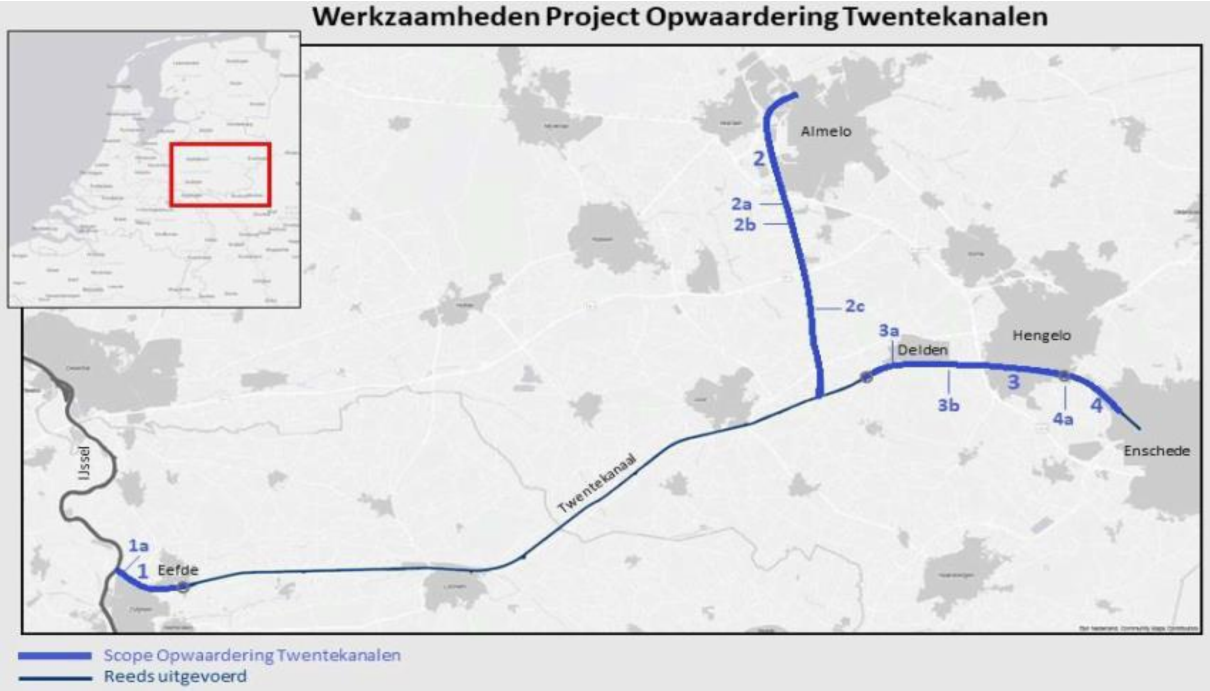


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometre points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **tensile lock tests** conducted on the composite sheet piles.

2 Test and material

This paper will present the results obtained from the tensile lock tests conducted on composite sheet piles. The test method does not align with any ASTM standard. In reality, this test is a self-devised procedure aimed at assessing the force the lock can endure before failing. The material is tested in a direction perpendicular (transverse) to the fibre direction. This choice is made because the lock is connected in the transverse direction of the composite sheet pile, making it impractical to test the lock in the longitudinal direction.

These sheet piles are constructed from pultruded glass fibre polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in³/ft	703.22	cm³/m
Moment of Inertia	54.01	in⁴/ft	7375.52	cm⁴/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in²	47.94	cm²
Standard Color	Graphite Gray			

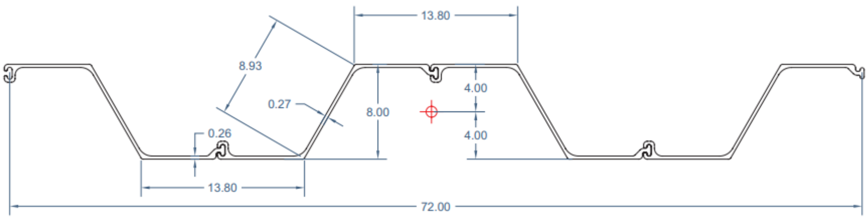
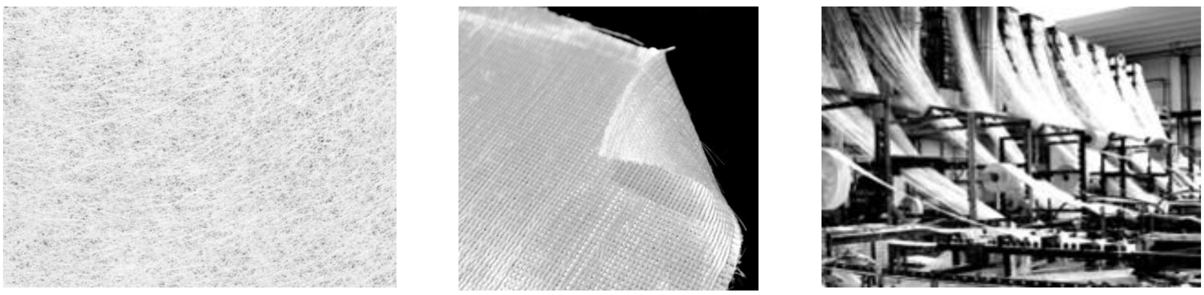


Figure 2-1 Superloc Series 1580

The glass fibre volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibres on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament 0/90 Fabric 0 Direction

Figure 2-2 Visual representation glass fibres used

3 Preparation and equipment used

The specimens for the tensile test of the lock part consist of two separate components, as detailed in Table 3-1. During the test, these two parts are slid together to form a single integrated specimen for testing. The width of the specimens used for the tensile lock test has been determined based on the dimensions of tensile tests conducted in the transverse direction according to ASTM D3039, with each specimen having a width of 25 mm. The length of the specimens is derived from the width of the flat sections of the composite sheet piles.

Appendix A includes the sawing plan for the samples obtained from the sheet pile elements, with only the samples labelled as 'STxx' being relevant for this test. The specimen samples were prepared using waterjet cutting at the Equipment and Prototype Centre of the Technical University in Eindhoven. Figures 8-1, 8-2, and 8-3 in Appendix A indicate the locations from which the samples were extracted from the sheet pile.

No specific consolidation methods were applied afterward, and the samples were stored in the test lab. No non-destructive test methods were conducted in advance of this test.

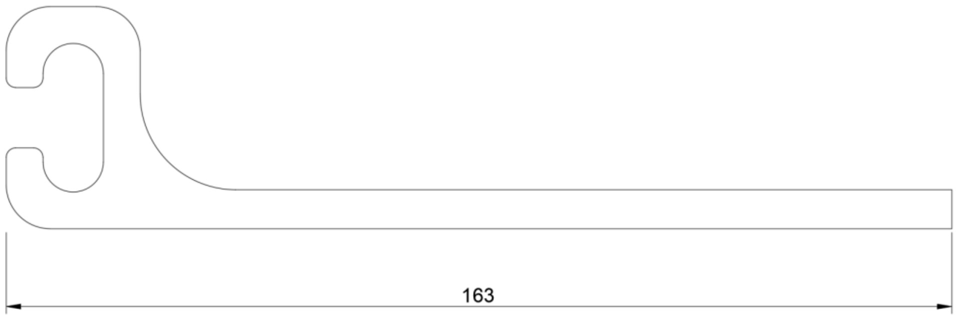
STxx (female lock part)	
STxx (male lock part)	

Table 3-1: Sample dimensions

For this test, an Instron 5985 machine manufactured on May 15, 2014, with a capacity of 250kN was utilized. The machine underwent its most recent calibration on February 14, 2022, by NMI Certin. Data was directly collected from the Instron machine using Bluehill Universal computer software to measure the material strain. The data was then exported as CSV files, which were subsequently imported into Excel for data processing.

The following raw data types were retrieved: Time, Force and Displacement.

A total of 5 tensile lock tests were conducted in the transverse direction of the material. A testing speed of 2 mm/min was employed for the tests. The samples were positioned in the Instron machine using the system depicted in Figure 3-1. Please take note of the stops that obstruct the sample, ensuring proper alignment with the machine's grips. The samples were secured using Precision Manual Wedge Grips, model number 2716-030. No tabs were utilized for testing as they were deemed unnecessary, given that the initial test results aligned with expectations. Under normal laboratory conditions, the relative humidity (RH) ranged from 40-50%, and the temperature was approximately

21 degrees Celsius. No other environmental-specific conditions were applied during the tests or the storage of the samples.

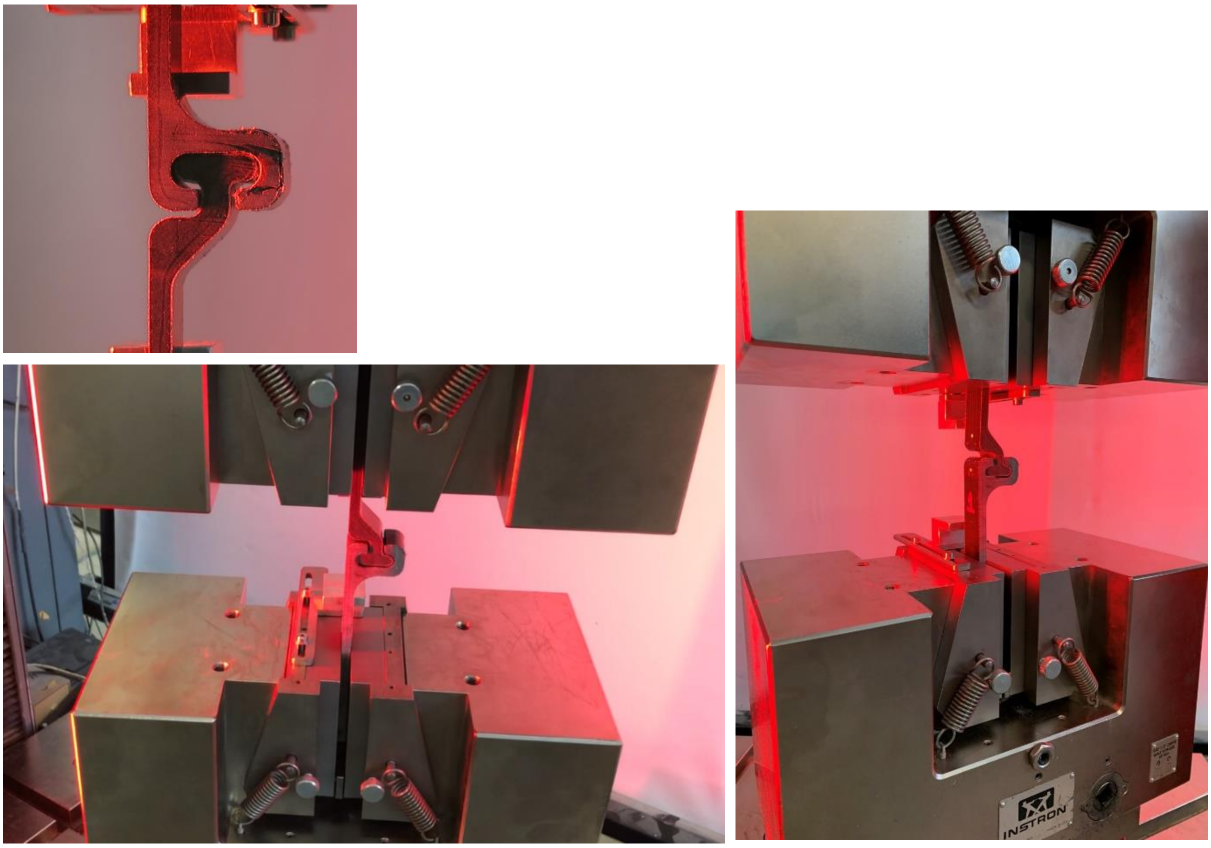


Figure 3-1 Sample alignment in the machine

4 Results

Figure 4 presents the Force vs. Displacement graphs for all 5 lock tests. Below, in Table 3-2, you can find the individual force vs. displacement graphs for each sample. The subsequent section will analyse the results and examine the failure modes.

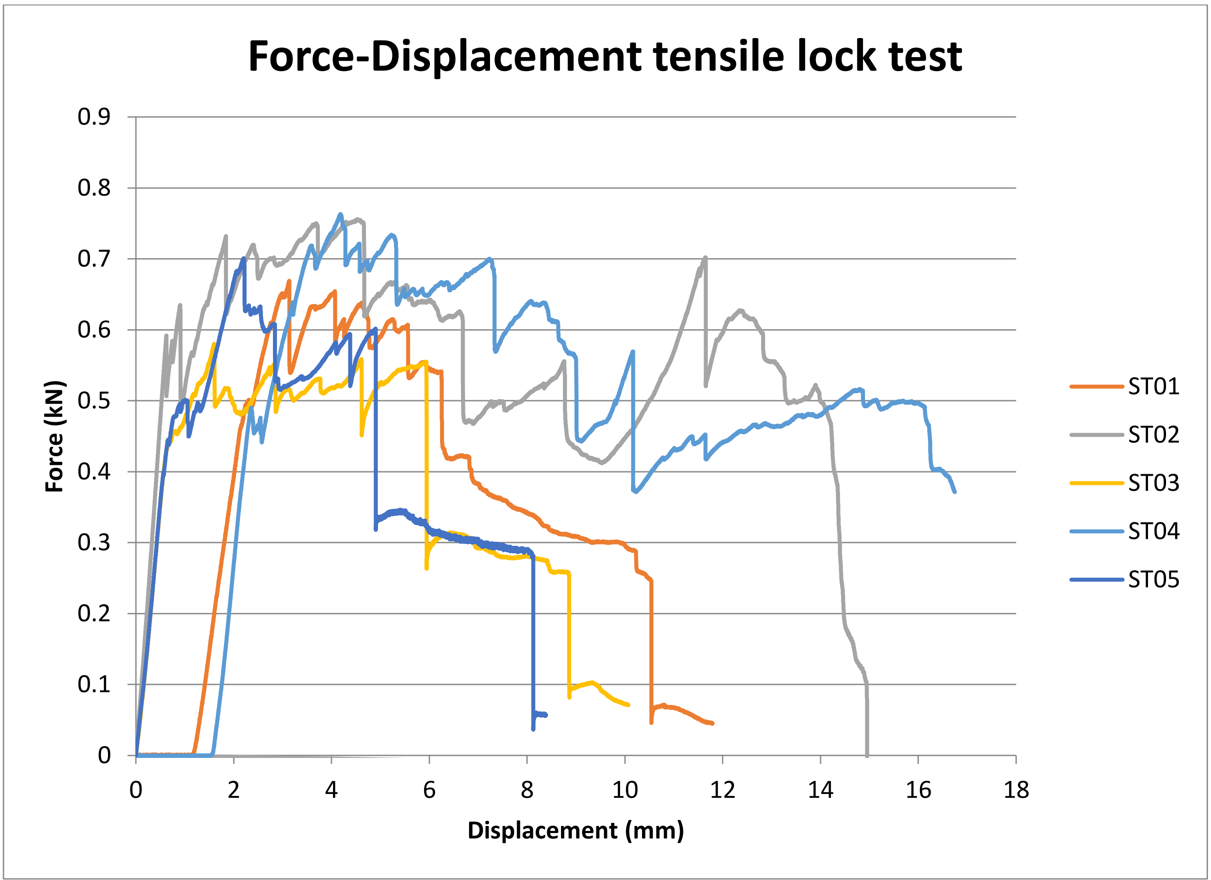
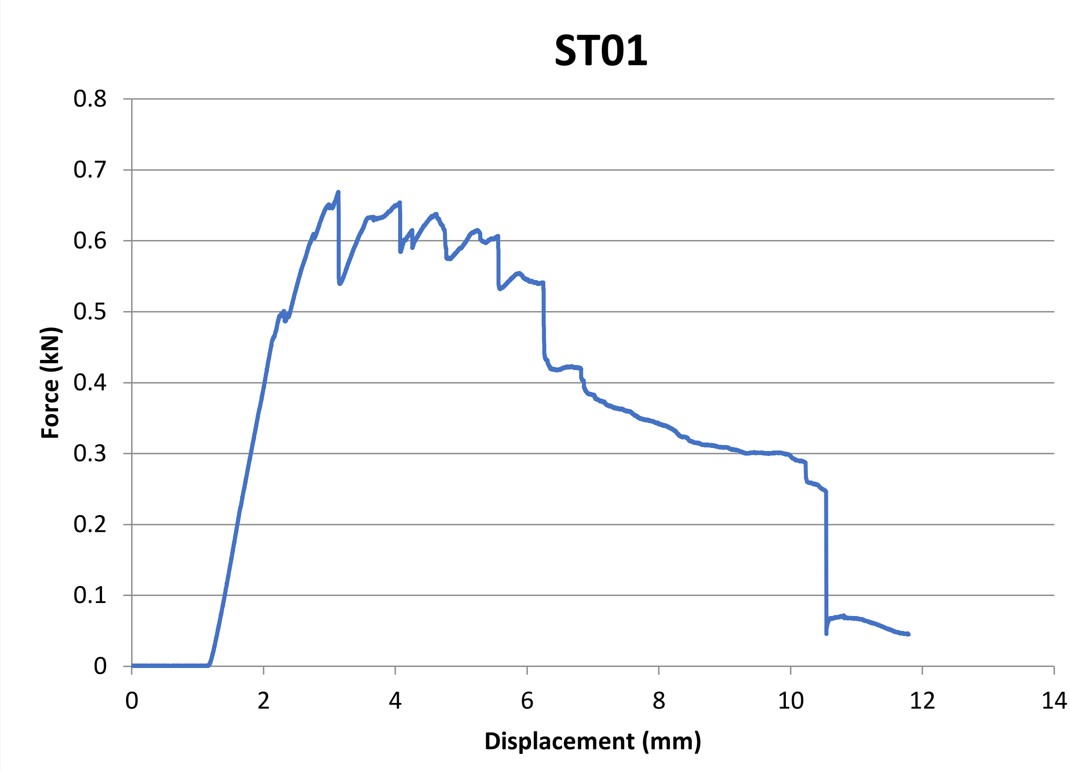
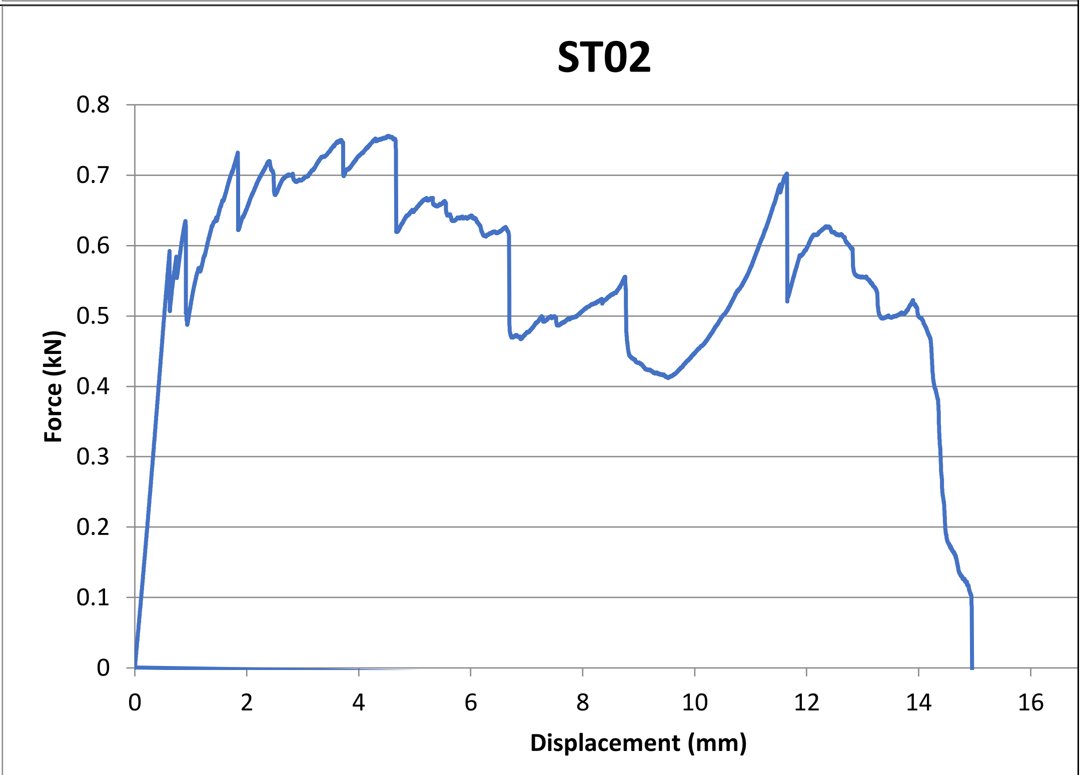
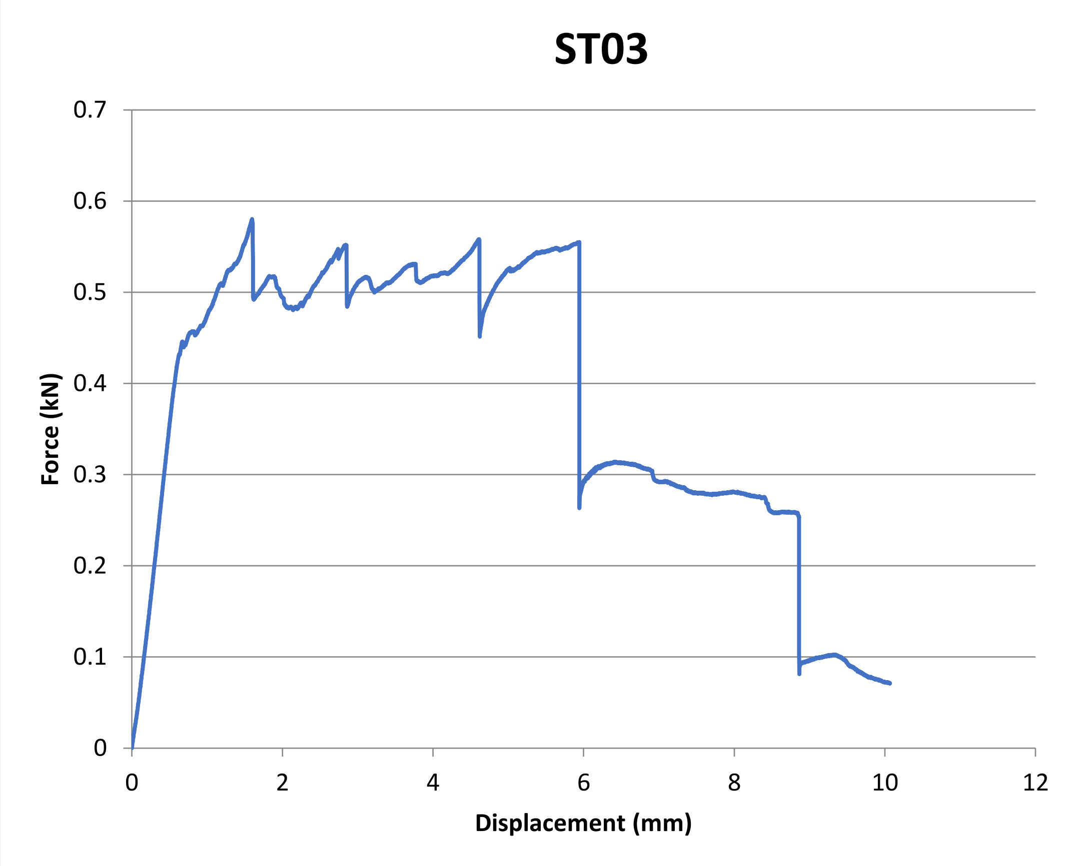
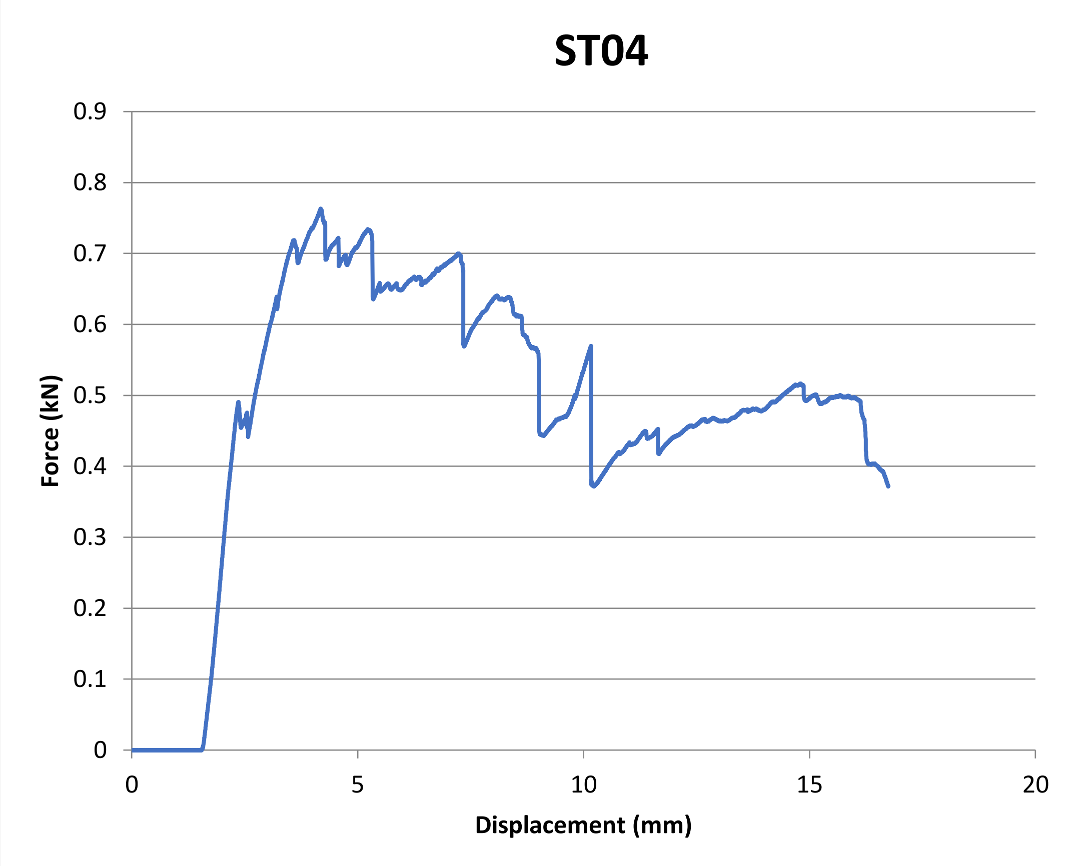


Figure 4-1 Force flexure displacement all tested samples

Test:	Force/Displacement graph
ST01	
ST02	

ST03	
ST04	

ST03
Force (kN)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Displacement (mm)

ST04
Force (kN)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
Displacement (mm)

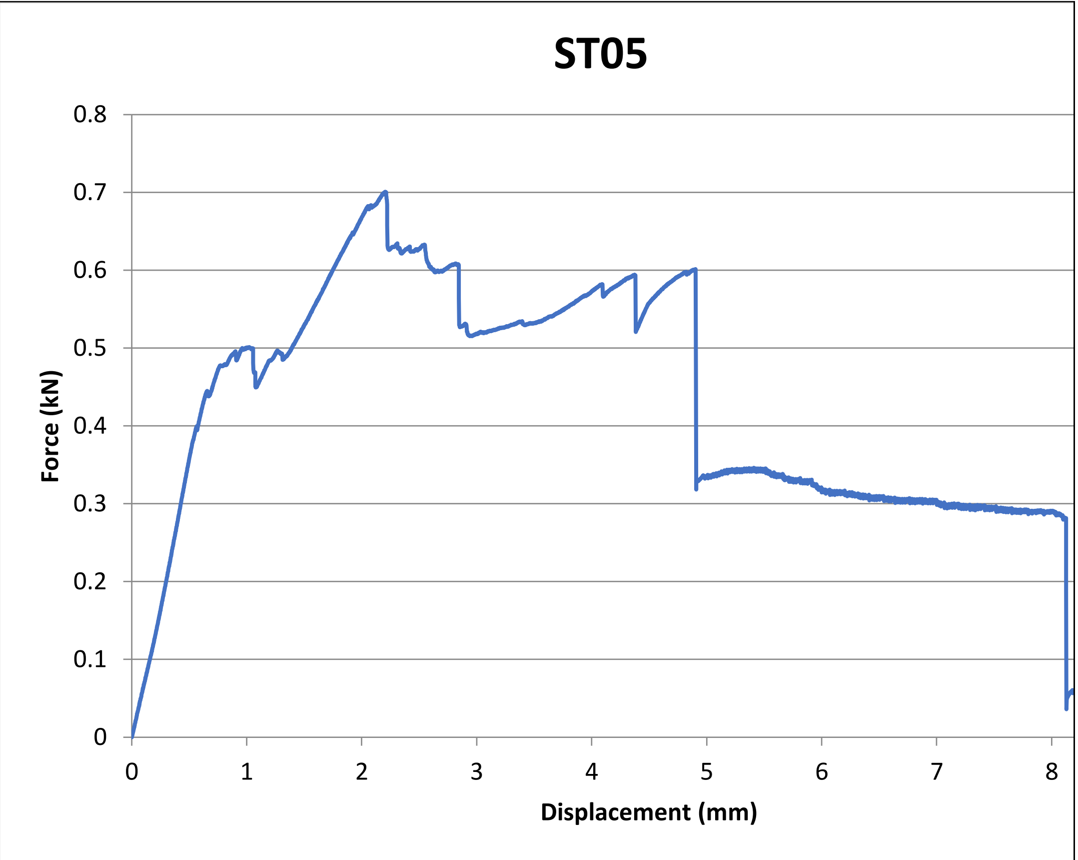
ST05	

Table 4-1: Individual force-displacement graph tensile lock test

5 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value

n = number of tests

V_x = Which is the coefficient of variation $V_x = S_x/m_x$

S_x = Standard deviation

m_x = average value

k_n = Static factor which can be calculated with $k_n = K* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.

K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 5-1: k_n values

6 Ultimate lock strength

Table 6-1 displays the failure force corresponding to the points where the graphs cease to rise linearly. Video footage revealed that at these points, the outer edges of the sheet pile element separate from the resin, and small cracks begin to appear. These cracks occur on the side where the resin detaches from the edge fibres. Refer to Figure 6-1 and 6-2 on the following page, which depict the initial failure mechanism in the sheet pile lock test.

Sample	Max Force (kN)	Deviation (kN)
ST01	0,50115	-0,013312
ST02	0,63469	0,120228
ST03	0,44587	-0,068592
ST04	0,49058	-0,023882
ST05	0,50002	-0,014442
Average (kN)	0,5145	
Standard deviation (kN)	0,06343	
Coefficient of variation (%)	12,33	
K	1,645	
kn	1,802	
n	5	
Rk (kN)	0,4002	

Table 6-1: Individual first failure force lock

Table 6-2 presents the maximum force that the sheet pile locks can withstand. This is the stage where the crack extends over a larger portion of the cross-section of the tested sample. As the test progresses, the cracks eventually extend throughout the entire cross-section, and within the locks, the outer fibres separate from the inner ones. Ultimately, the locks can be pulled apart from each other. Refer to Figure 6-3 and 6-4 on the following page, which depict the final failure mechanism of the tested elements.

Sample	Max Force (kN)	Deviation (kN)
ST01	0,66899	-0,024804
ST02	0,75568	0,061886
ST03	0,58043	-0,113364
ST04	0,76294	0,069146
ST05	0,70093	0,007136
Average (kN)	0,6938	
Standard deviation (kN)	0,06653	
Coefficient of variation (%)	9,589	
K	1,645	
kn	1,802	
n	5	
Rk (kN)	0,5739	

Table 6-2: Individual maximum failure force lock

6.1 Failure mode

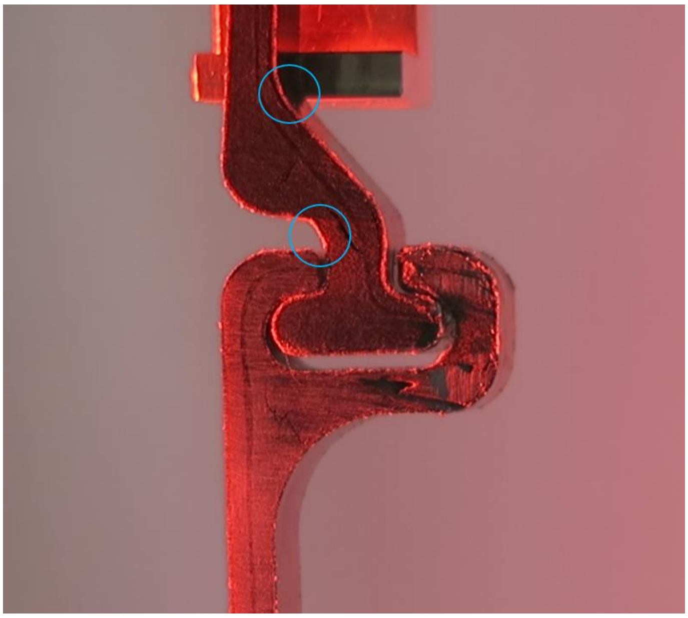


Figure 6-1 First failure signs (1)

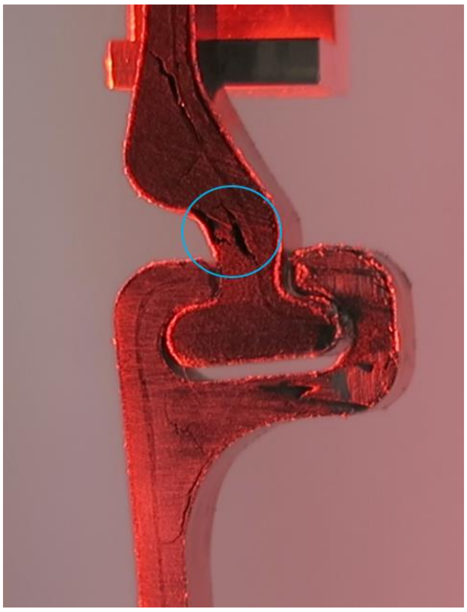


Figure 6-2 First failure signs (2)

Figure 6-3 Final failure mechanism (1)

Figure 6-4 Final failure mechanism (1)

7 Summary

Summarizing the results from the tensile lock tests, the following outcomes are obtained and presented in Table 7-1.

Results lock	
Characteristic 1st tensile lock strength	0.40 kN
Characteristic tensile lock strength	0.57 kN

Table 7-1: Characteristic tensile lock properties, retrieved from the tests.

8 Appendix

8.1 Appendix A – Sample numbering

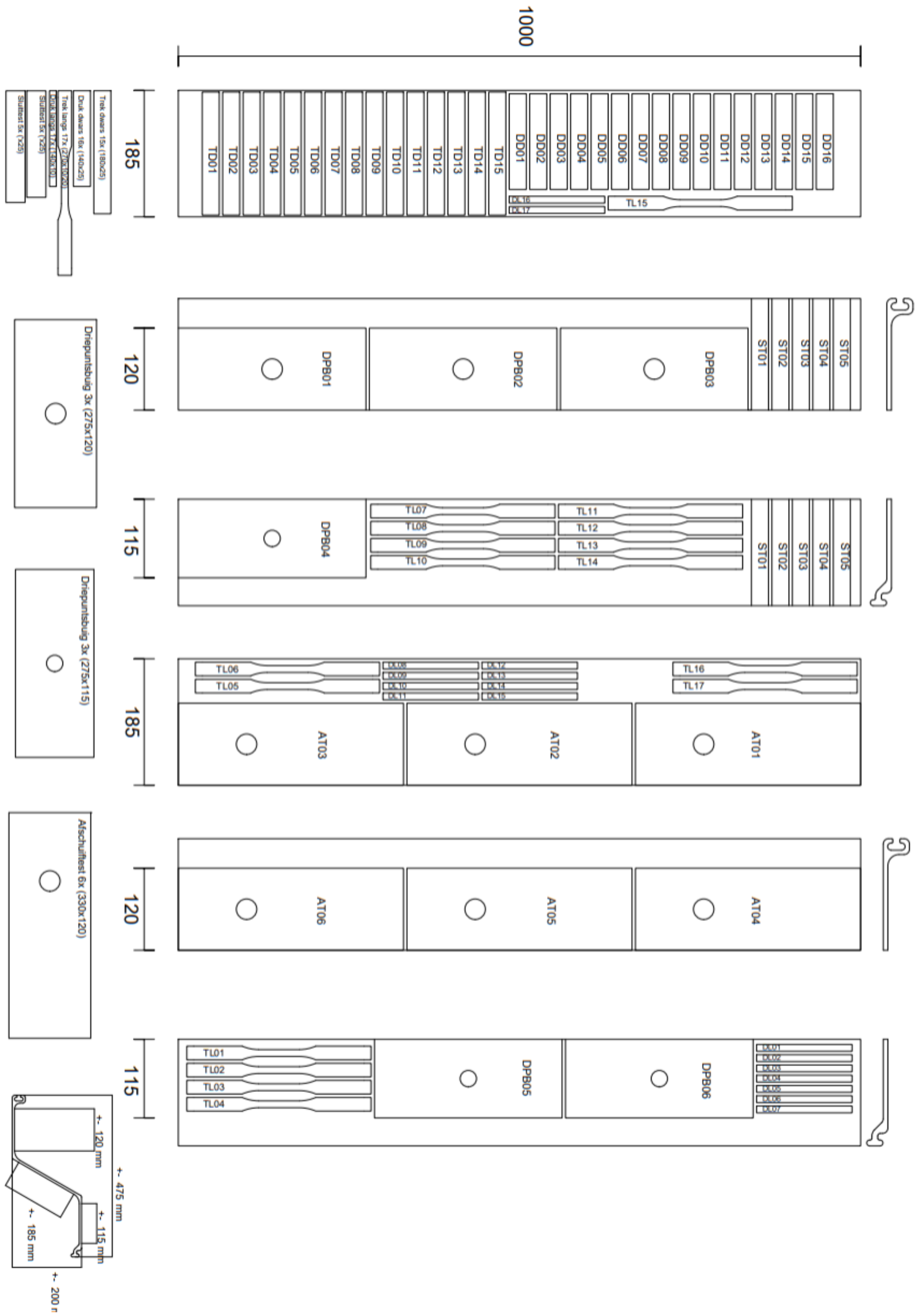


Figure 8-1 Saw plan all samples

Figure 8-2 Samples retrieved from sheet

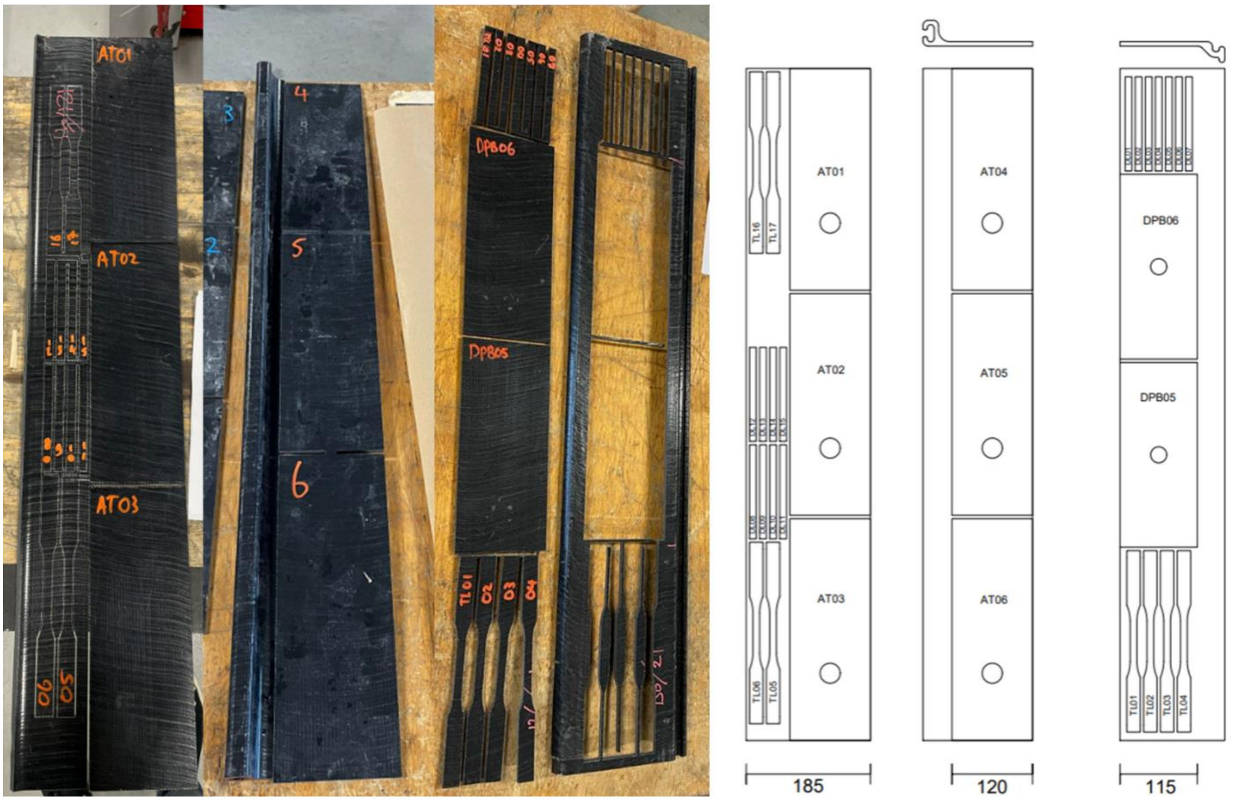
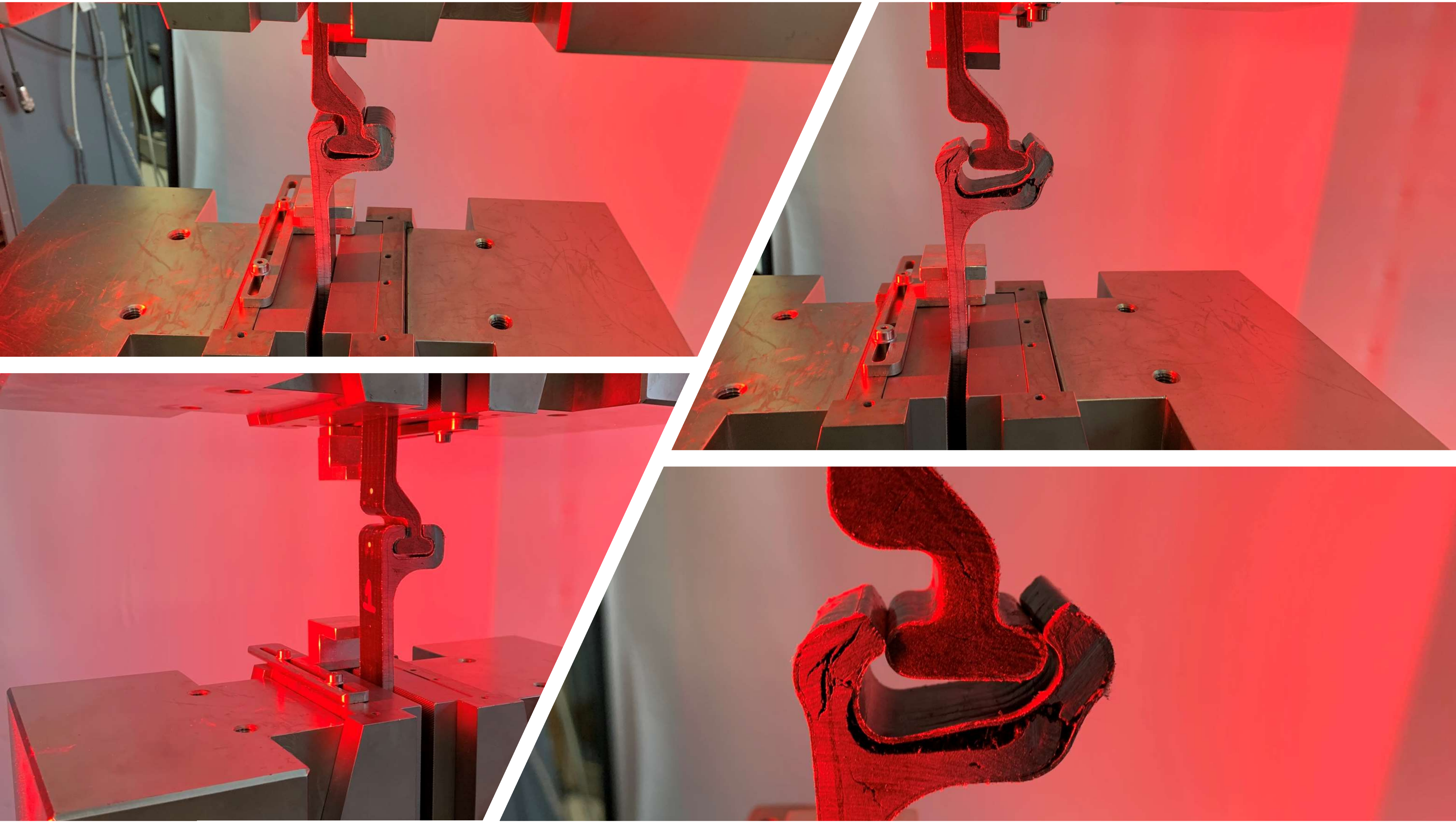
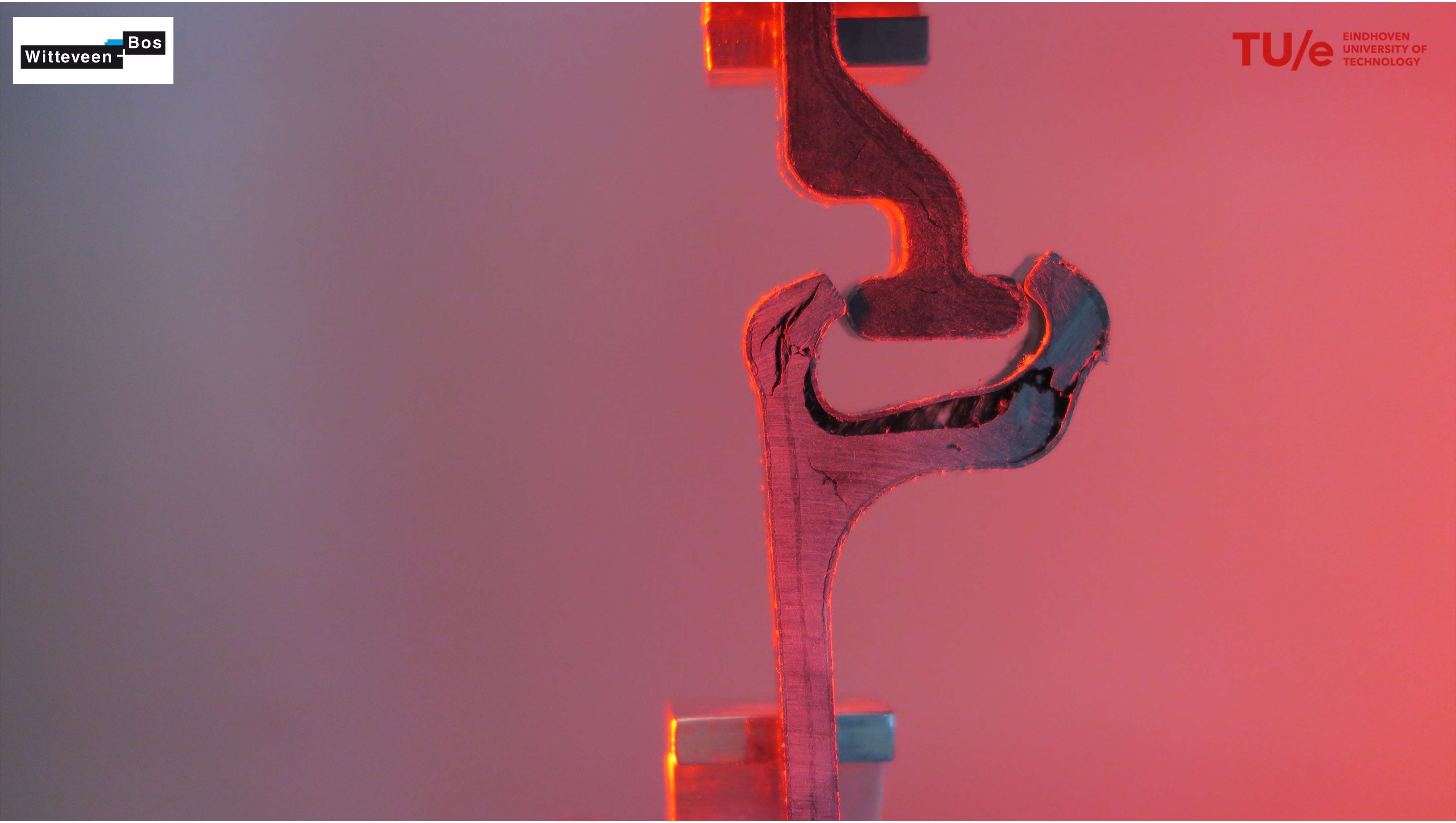


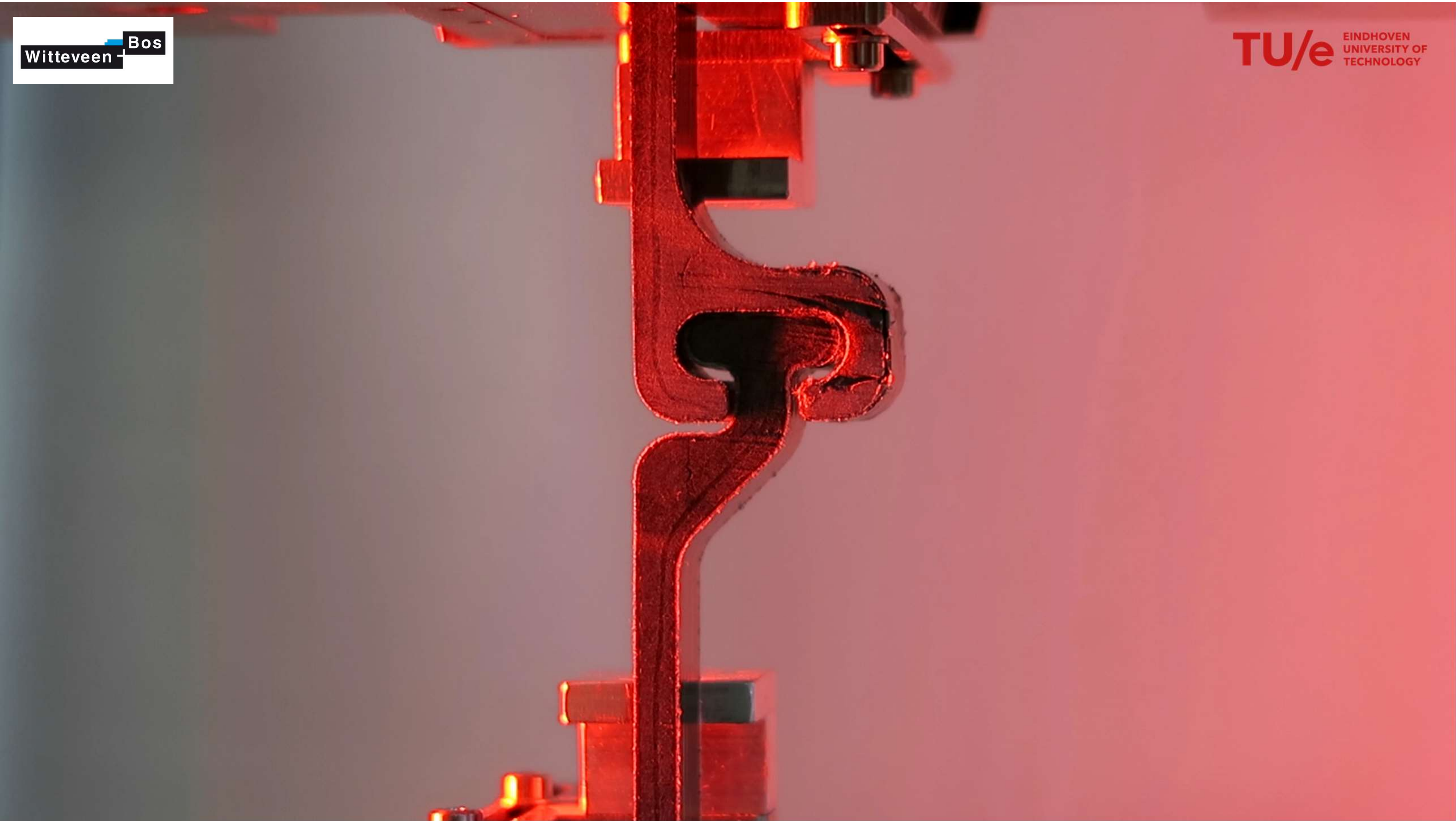
Figure 8-3 Samples retrieved from sheet

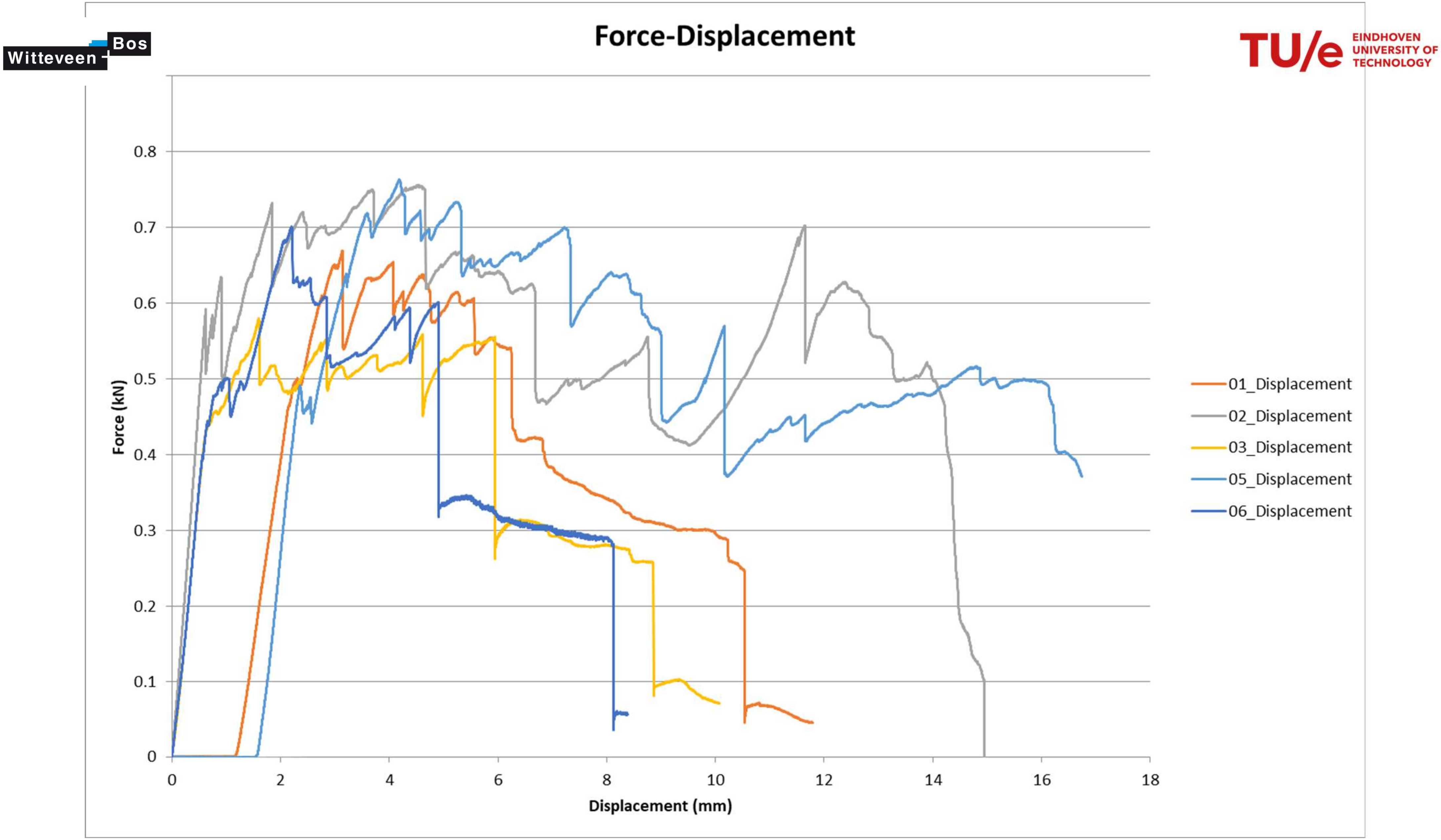
8.2 Appendix B – Presentation results and test

Tensile lock test composite sheet piles




Witteveen + Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

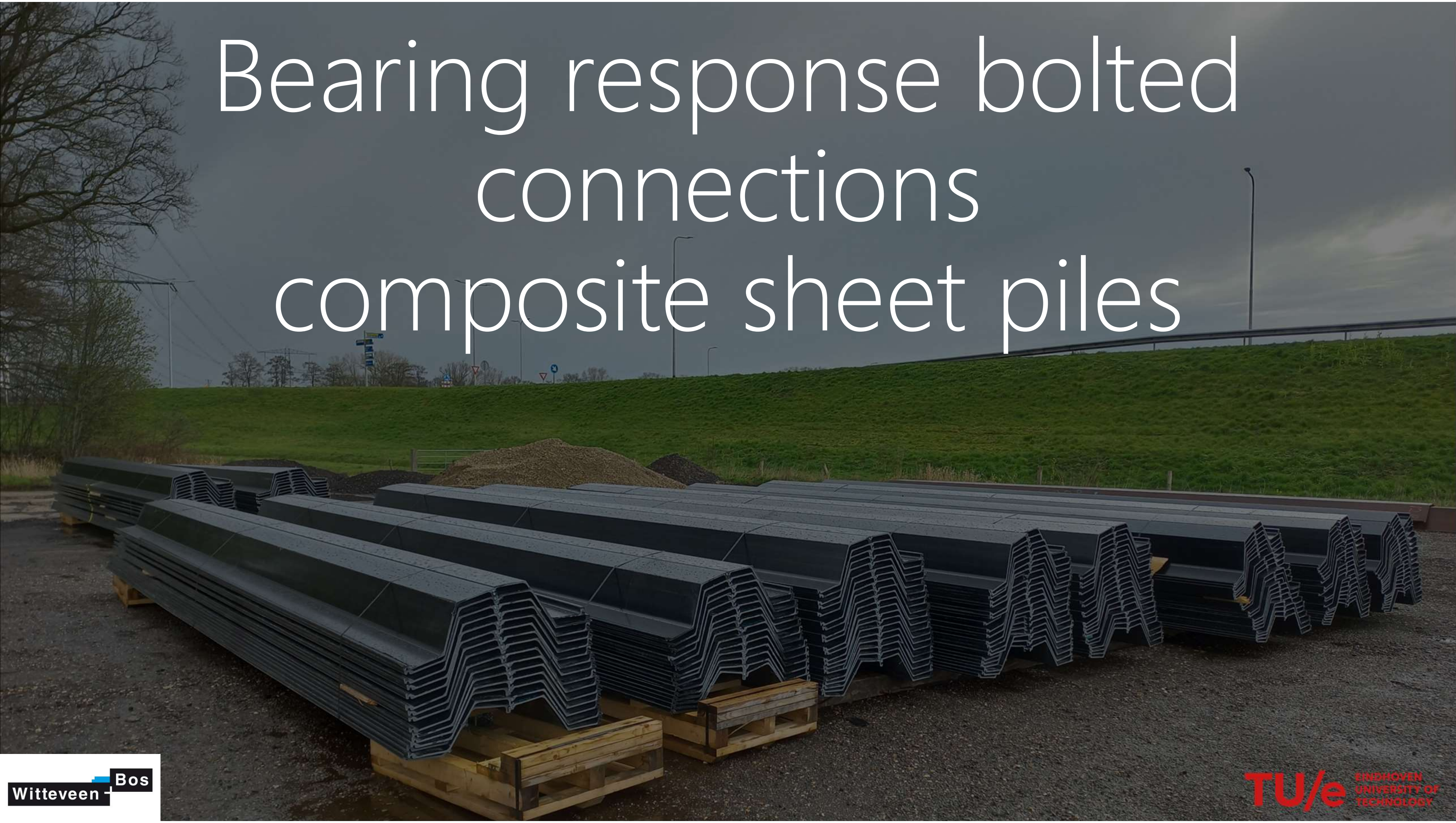




Witteveen + Bos
Force-Displacement
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Force (kN)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
2
4
6
8
10
12
14
16
18
Displacement (mm)
01_Displacement
02_Displacement
03_Displacement
05_Displacement
06_Displacement

5.7 Appendix G – Report Bearing response bolted connections

Bearing response bolted connections composite sheet piles

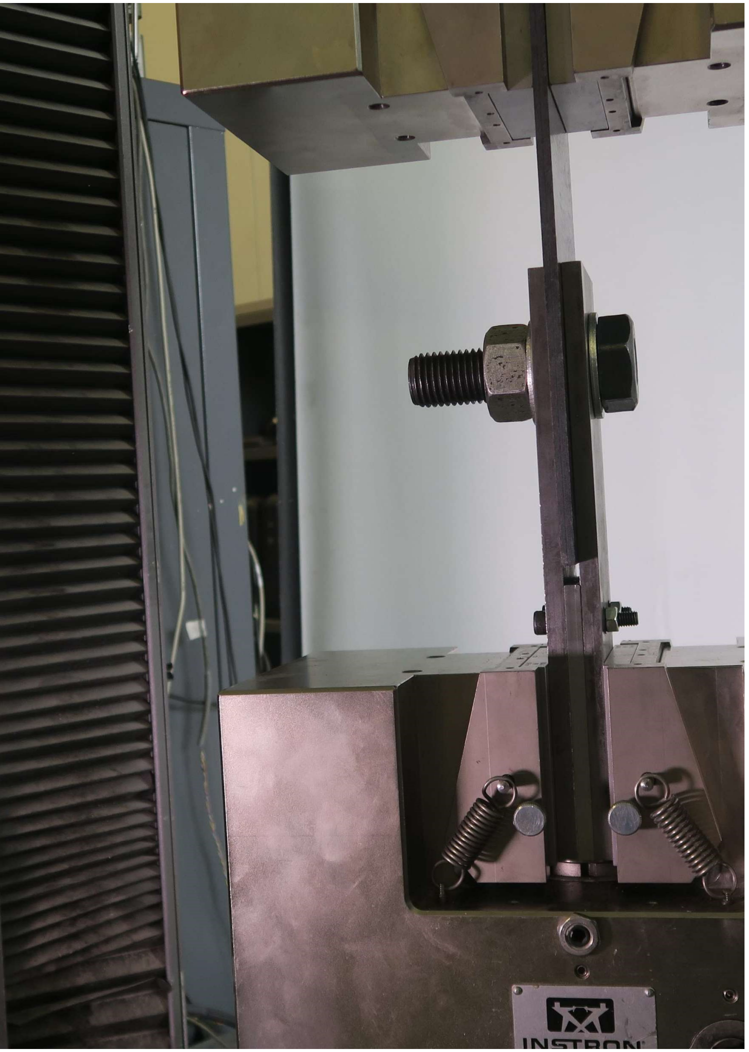


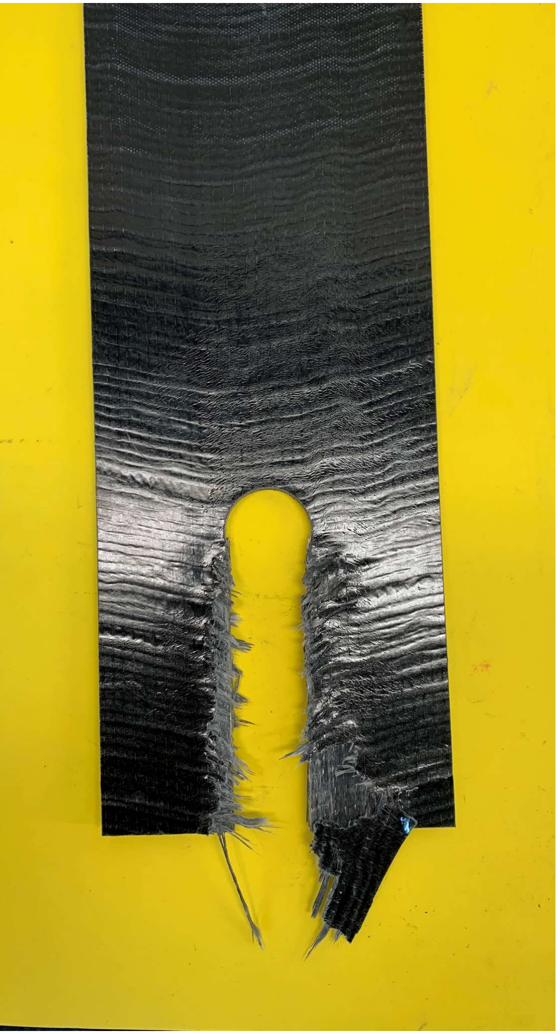
Witteveen+Bos

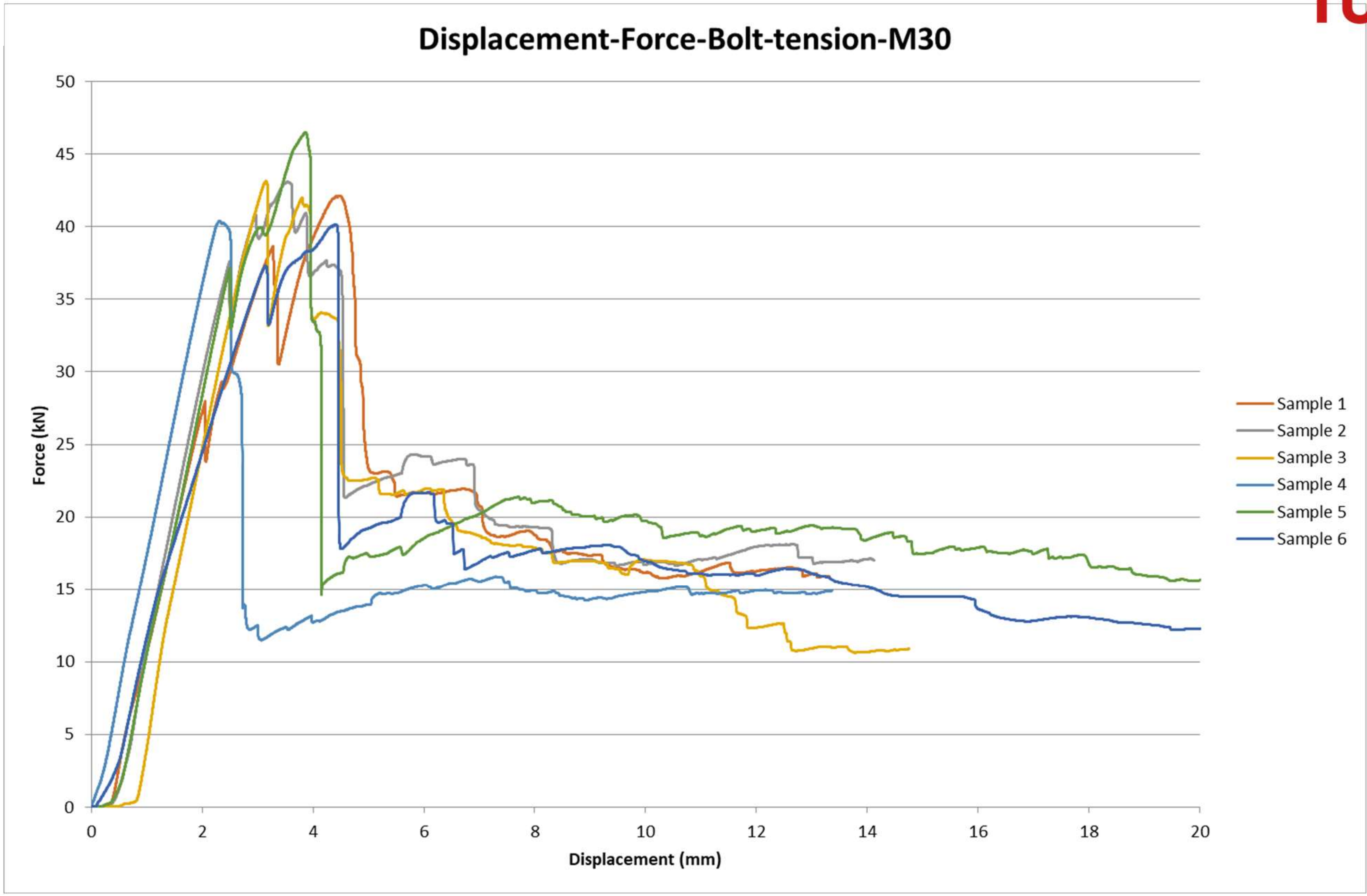
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Witteveen+Bos

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY



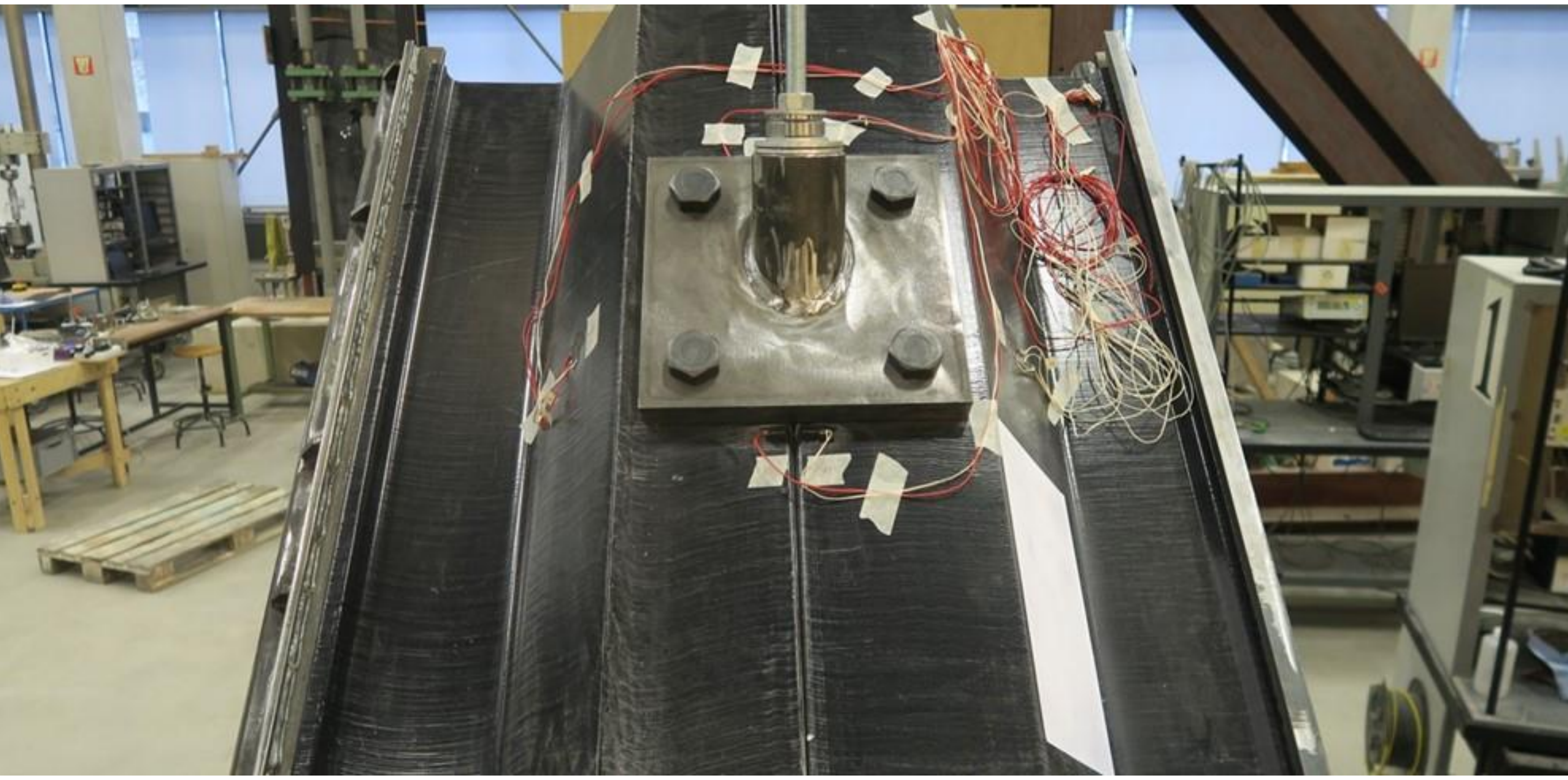



Displacement-Force-Bolt-tension-M30
Force (kN)
Displacement (mm)
0
5
10
15
20
25
30
35
40
45
50
0
2
4
6
8
10
12
14
16
18
20
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 6

5.8 Appendix H – Report full scale tests lab

Full-scale lab. test composite sheet piles

-



Project name: Opwaardering Twentekanalen
Client: Rijkswaterstaat GPO
Contractor: Combinatie Van Oord, Hakkers, Beens
Sub-contractor: Witteveen+Bos, TU/e, Dept. of Built Environment

Status: Final
Revision: 2.0 – 13-10-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0	Prepared by			
	Checked by			
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0	17-03-2023	Final Version
2.0	13-10-2023	Update

Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date test 1:	21-04-2023
Date test 2:	25-05-2023
Test standards:	-
Material:	E-glass, polyester
Specimen type:	1 meter full scale section
Pre-treatment:	21 °C / 45-50% RV
Machine:	self made construction with hydraulic jack
Pre-load:	0 MPa
Test speed:	5 kN/min
Angle:	45 degrees
Anchor plate test 1:	300 x 300 x 30
Anchor plate test 2:	300 x 300 x 30 + fill plate
Bolts:	4 x M30
Filler test 1:	Steel
Filler test 2:	Softwood

Table of content

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

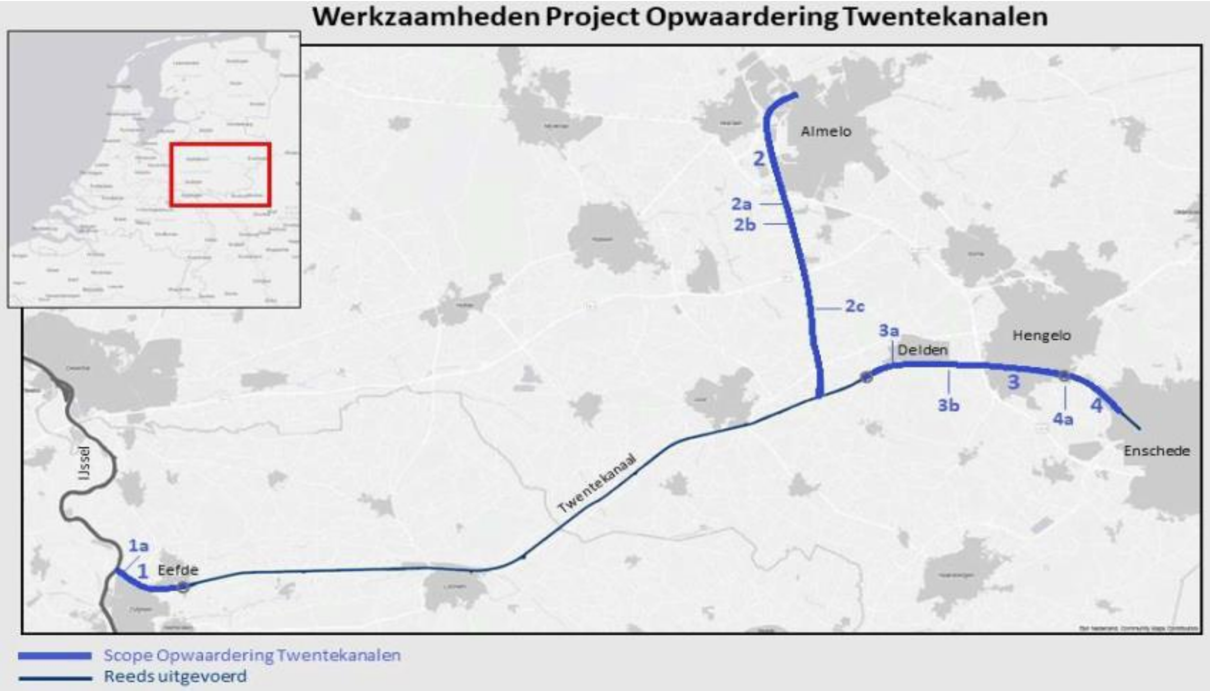


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometre points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **full-scale lab tests** conducted on the composite sheet piles. The primary objective of this test is to evaluate the response of the sheet piles when subjected to varying anchor forces. The focus lies on assessing the interaction between the sheet piles, anchor plate, and anchor under different loading conditions.

The findings from this laboratory test are anticipated to contribute valuable insights into the performance and behavior of composite sheet piles under specific anchor forces. These insights will be instrumental in refining design considerations and optimizing the implementation of composite sheet piles in practical applications. This report provides a detailed overview of the testing methodology, experimental setup, and preliminary observations, paving the way for a deeper understanding of the dynamic interactions between composite sheet piles and anchoring systems.

In order to implement composite sheet piles on a large scale in the Netherlands, it is crucial to adapt these sheet piles to the specific soil conditions prevalent in the country. In Dutch construction practices, steel sheet piles with grout anchors are commonly utilized. The grout anchor is inserted into the ground at an angle and tensioned against an anchor plate mounted on the sheet pile or the wale. Composite sheet piles must demonstrate the capability to withstand comparable anchor forces as possible on steel sheet piles.

Typically composite sheet piles are equipped with low-capacity anchors due to limited force transmission with the composite material. The commonly used self-drilling anchors in the Netherlands are efficient in that they can withstand high forces and can be implemented with minimal environmental impact. The combination of high anchor forces and composite sheet piles has never been attempted before. This implies that the composite sheet pile will be subjected to a loading condition that has not been tested previously, and the actual capacity of the composite sheet pile under such loading is uncertain. Laboratory tests will be conducted to gain insight into local failure mechanisms, especially buckling.

2 Test and Material

This paper will present the results obtained from two full-scale lab. tests conducted on 1 meter long composite sheet piles. The tested composite sheet piles are 1 meter in length and have been strategically positioned within a frame at a 45-degree angle. This angle has been chosen to replicate a common anchoring scenario prevalent in the Netherlands. To simulate realistic conditions, hydraulic jacks have been employed to apply anchor forces during the test, providing a thorough representation of field scenarios.

These sheet piles are constructed from pultruded glass fibre polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in³/ft	703.22	cm³/m
Moment of Inertia	54.01	in⁴/ft	7375.52	cm⁴/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in²	47.94	cm²
Standard Color	Graphite Gray			

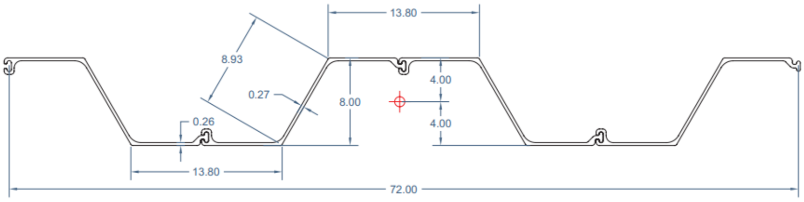
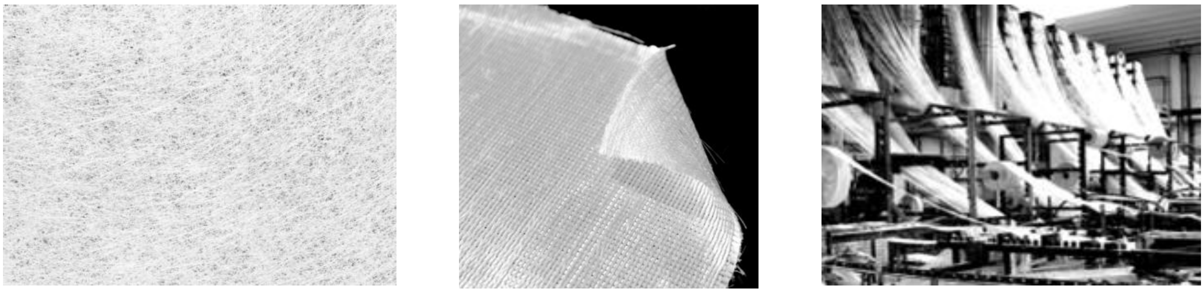


Figure 2-1 Superloc Series 1580

The glass fibre volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibres on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament | 0/90 Fabric | 0 Direction

Figure 2-2 Visual representation glass fibres used

3 Preparation and equipment used

The sheet piles used for this test were provided to us by the Creative Composite Group. The sheet piles are being meticulously trimmed to a length of 1 meter by a circular saw under controlled conditions by the producer and shipped to the Netherlands.

Figure 3-1 Samples

We opted for a commonly used type of anchor plate in the Netherlands, composed of a steel plate with an anchor tube mounted on it. The anchor plate is positioned on the belly of the sheet pile and falls within the flanges. After test 1, the anchor plate was widened so that it protrudes over the flanges to induce a different failure behaviour.

To test the sheet piles for anchor loading at a 45-degree angle, a specialized laboratory setup was created. This involved using a steel frame in which the sheet pile is positioned at a 45-degree angle. A hole was drilled in the sheet pile for the anchor rod, and an anchor plate 300 x 300 x 30 was attached to the sheet pile using four M30 bolts. The anchor rod is connected to a hydraulic tensioning jack.

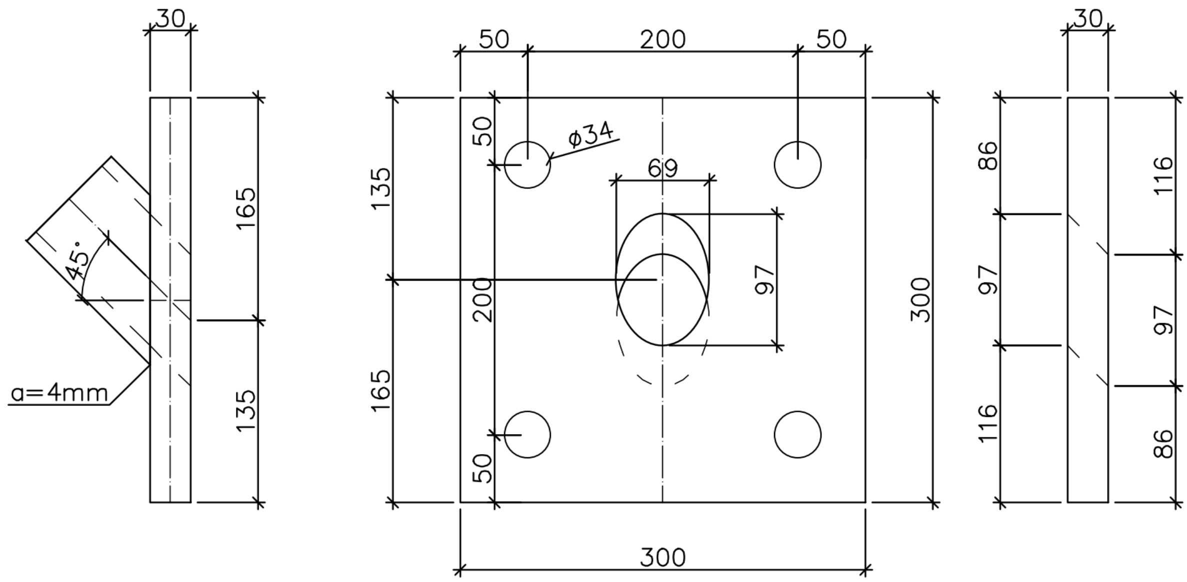


Figure 3-2 Anchorplate test 1

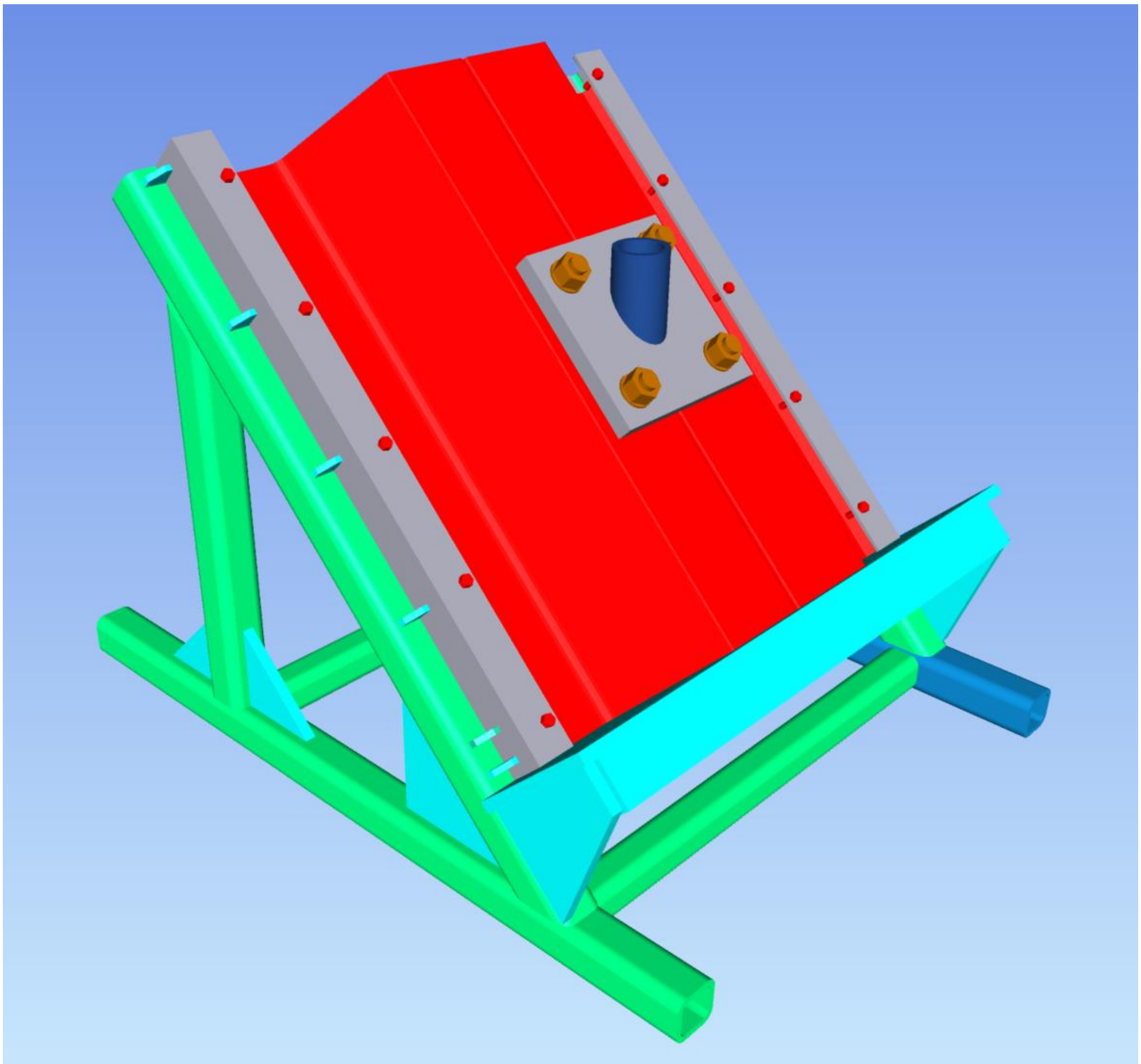


Figure 3-3 3D production model anchor frame

To assess the capacity of composite sheet piles under anchor loading, a test setup has been established using a steel anchor frame set at a 45-degree angle. The design of the anchor frame is attached in the appendix.

The anchor frame is designed to confine the sheet piles in the transverse direction, simulating the restraint of the sheet pile movement in the ground. The constraint in the ground is provided by both the soil resistance and the connection with the wale beam, as well as the interconnection of the sheet piles themselves. At the bottom, the sheet piles rest on a steel support to prevent vertical displacements. On the backside of the sheet pile, a steel box girder is installed, simulating a wale beam. This is where the sheet pile can brace itself.

The anchor frame is installed on a custom-made steel structure constructed from "Meccano" beams to accommodate a tensioning jack. This tensioning jack is positioned beneath the sheet pile to simulate the anchor force. The tensioning jack is connected to a hand jack that allows for pressure regulation. The anchor rod running from the anchor plate to the tensioning jack is equipped with a ball joint to prevent jamming in case the tension rod becomes skewed during the test. The jack pressure is converted into a force that is monitored. In total, two tests were conducted, with the sheet pile in the first test fitted with strain gauges that are read in real-time. After analyzing the results, it was found to be too labor-intensive to convert the measured strains into a suitable FEM model, and it did not provide significant additional value. Therefore, it was decided to conduct the second test without strain gauges.

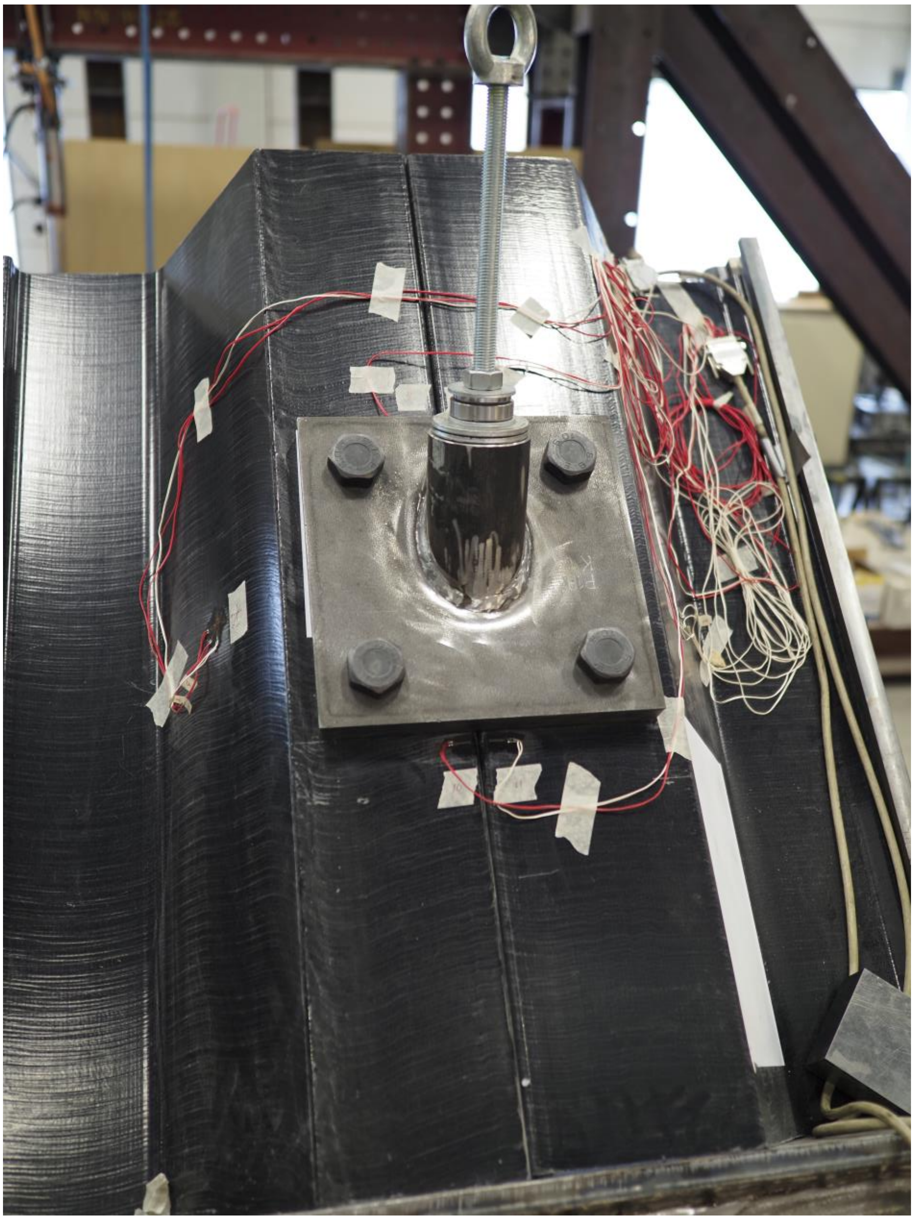


Figure 3-4 Sheet piles with strain gauges

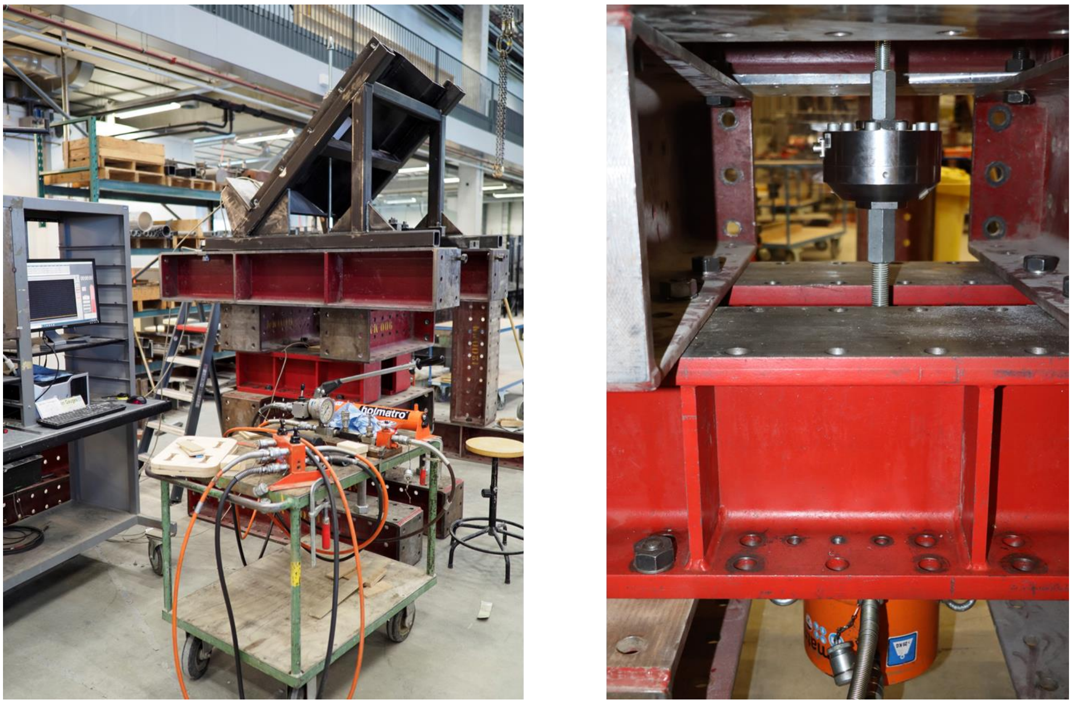
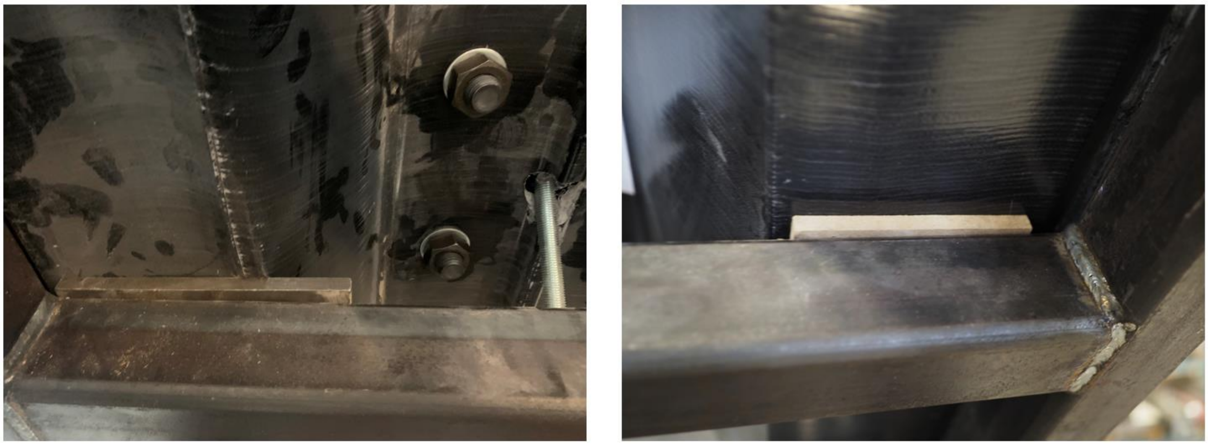


Figure 3-5 test set-up

The strain gauges and the hydraulic jack are linked to a computer that collects the acquired data. This data is then exported as CSV files and subsequently imported into Excel for data analysis. The raw data collected equals: Time, Force, Displacement. In total three tests have been conducted:

1. Anchor plate type 1 (300x300) with softwood filler plates in between sheet pile and wale beam (100 mm);
2. Anchor plate type 2 (300x300 + fill plate overlapping the belly of the sheet pile) with softwood filler plates in between sheet pile and wale beam (100 mm);
3. Anchor plate type 2 (300x300 + fill plate overlapping the belly of the sheet pile) with steel filler plates in between sheet pile and wale beam (100 mm).



Steel filler

Softwood filler

Figure 3-6 Filler types

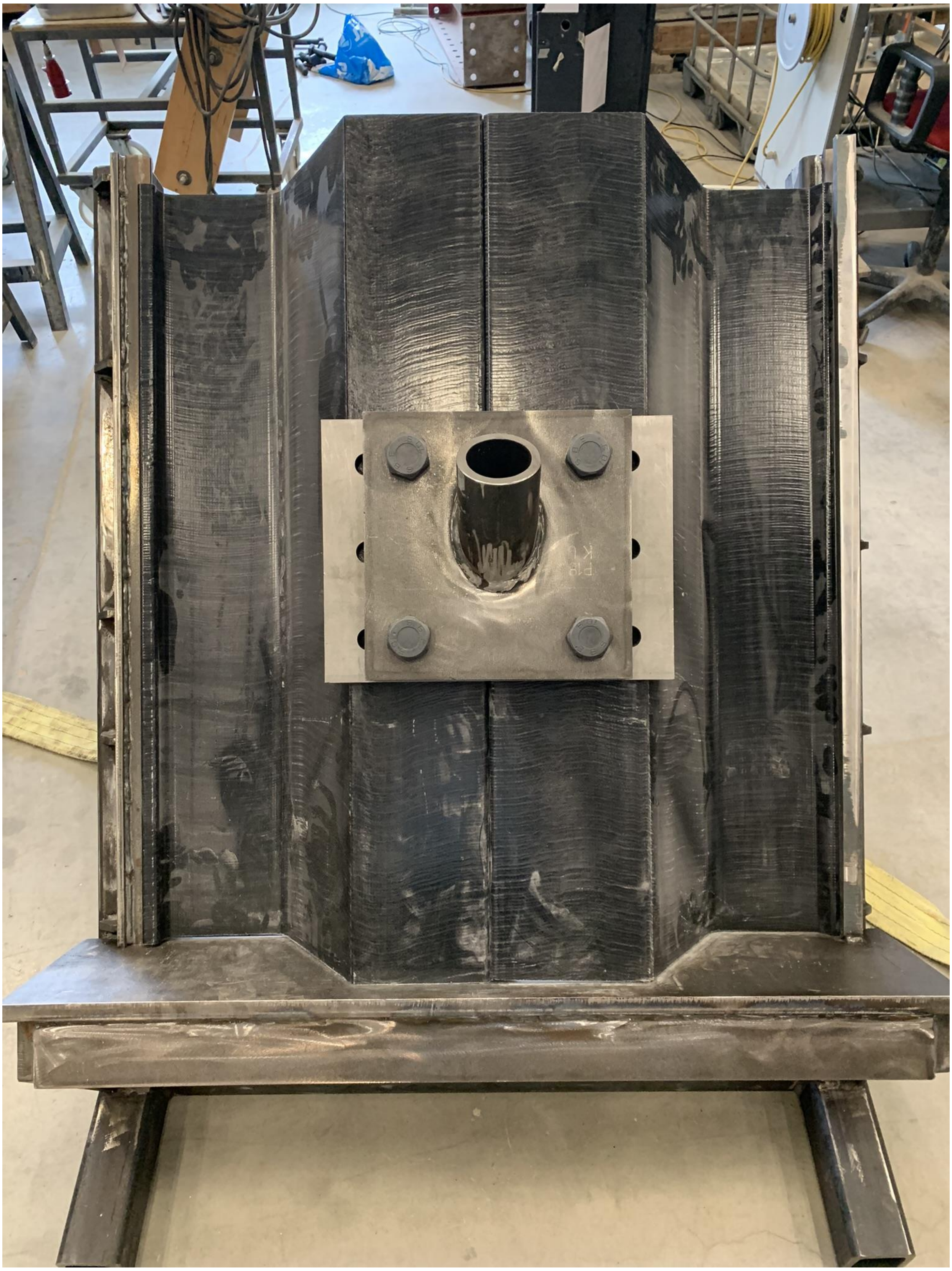


Figure 3-7 Anchor plate type 2 with filler plate

4 Results

Figures 4-1 and 4-1 display the force-versus-displacement curves for the tests conducted. Important to notice that the measured displacement are the displacements of the hydraulic jack. We did not measure the displacement of the sheet pile itself.

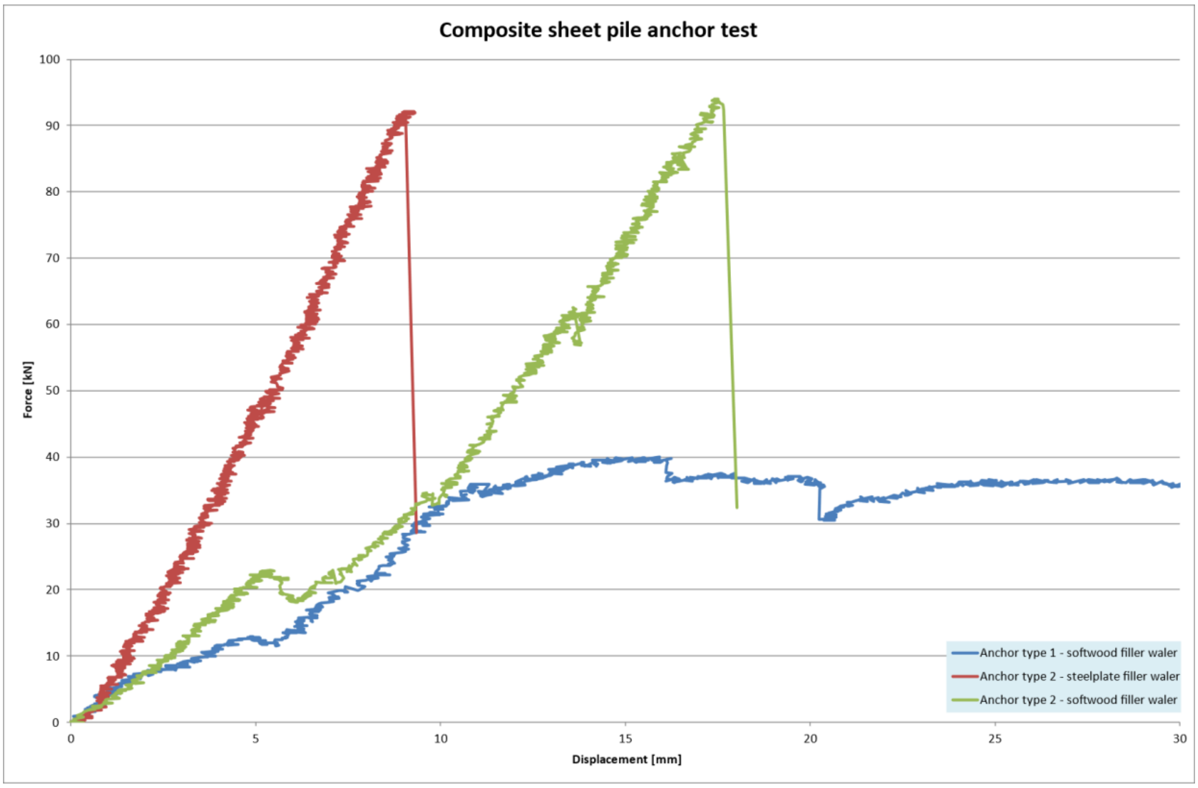


Figure 4-1 Force displacement

The composite sheet pile with anchor type 1, locally collapses due to the punching of the plate through the belly of the sheet pile. The graph shows significant displacement at a relatively low load. Initially, the plate compresses the softwood between the plate and the wale beam, and then the sheet pile begins to deflect. Because the steel plate is relatively much stiffer, the deflection of the sheet pile is limited, and the steel plate slowly cuts/punches through the first layer of the sheet pile, causing failure. This process continues until the plate is completely pulled through the sheet pile. The composite sheet pile with anchor type 1 fails due to punching shear.

Anchor plate type 2 has been modified to eliminate punching shear failure. With the new plate configuration, the sheet pile, in its current form, is optimally loaded. Two tests were conducted with anchor plate type 2, using different filling materials between the wale beam and the sheet pile. As expected, the infill with a softer material results in greater deformation, but the failure behavior remains the same. In both cases, the sheet pile fails due to local buckling.

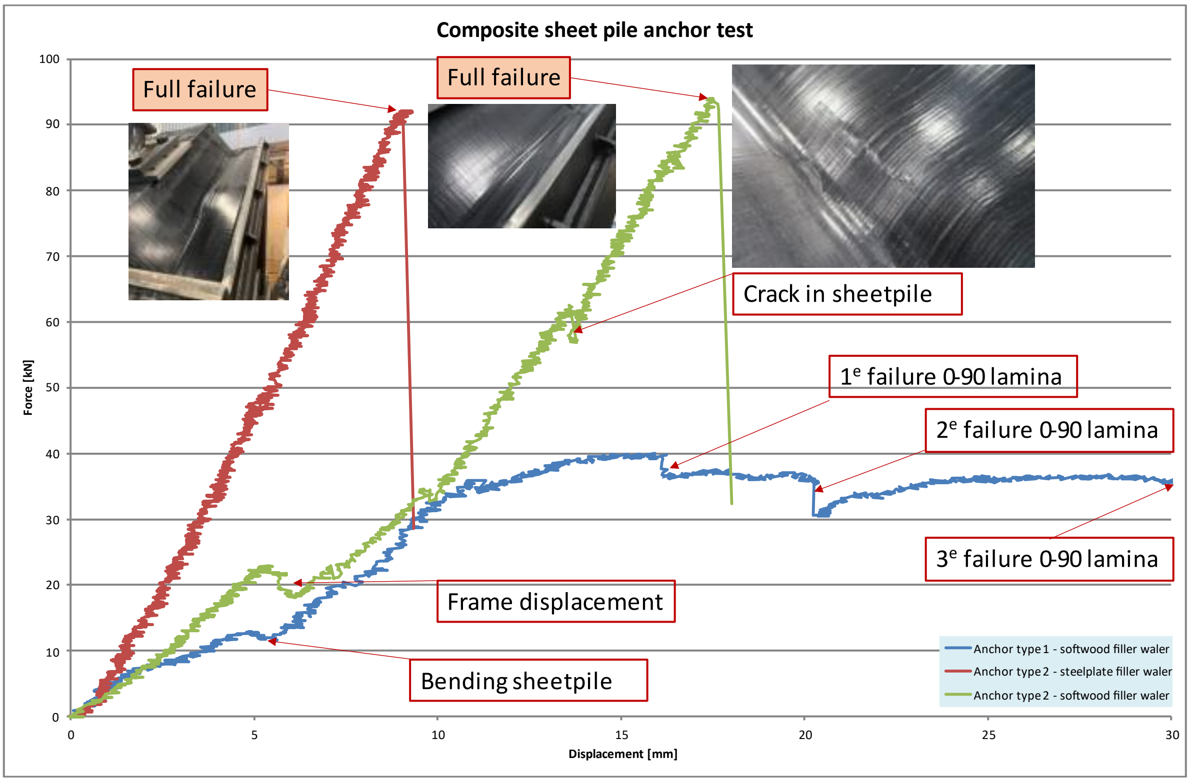


Figure 4-2 Force displacement including explanation

Because the force on the hydraulic jack is manually controlled by pumping, it results in an erratic pattern in the graph. Additionally, in the test with anchor type 2 and a softwood infill, the frame shifted. Both phenomena have been corrected to achieve a smoother trend in the graph. The green line is partially dashed because, on one side, the flange locally tore due to the load but did not fail. From a mathematical standpoint, the plank may no longer be deemed suitable. However, in terms of actual safety, there is still ample reserve capacity until the plank truly fails by local buckling.

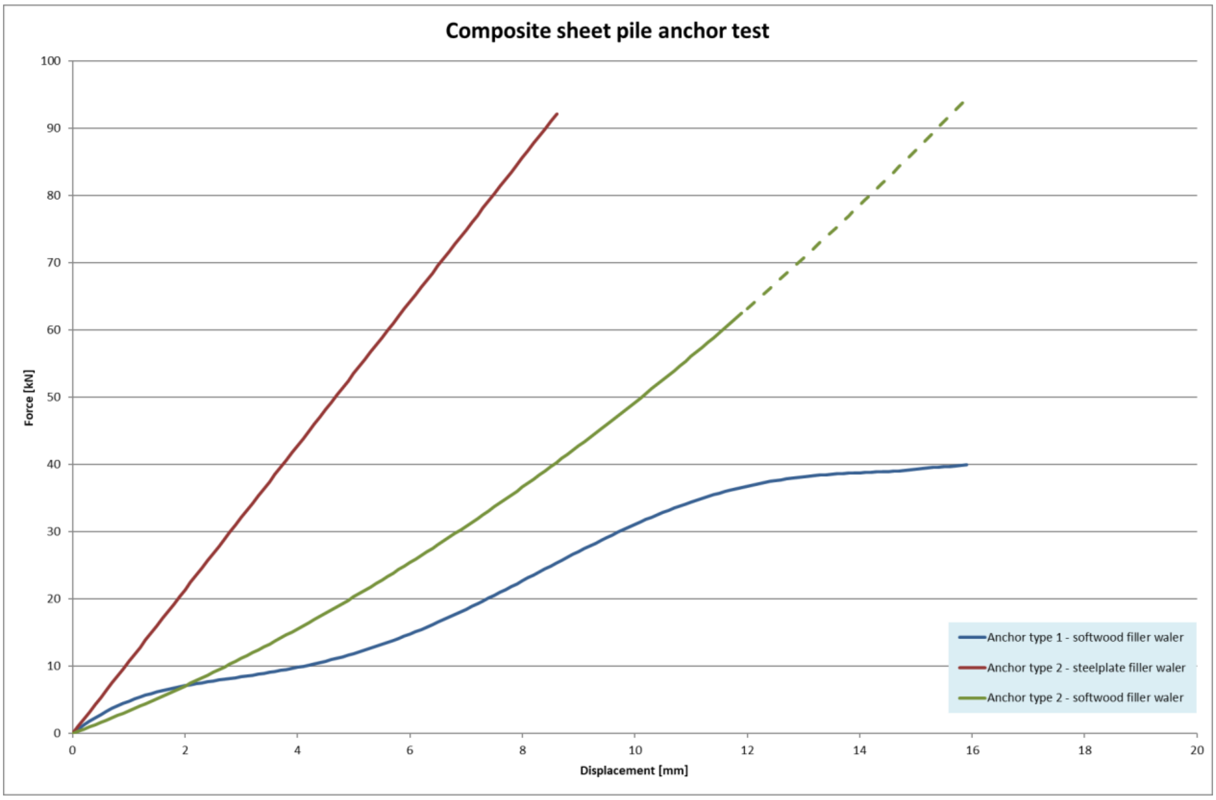


Figure 4-3 Force displacement smoot lines

5 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value

n = number of tests

V_x = Which is the coefficient of variation $V_x = S_x/m_x$

S_x = Standard deviation

m_x = average value

k_n = Static factor which can be calculated with $k_n = K* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.

K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 5-1: k_n values

Determining the characteristic value, in this case, does not add much value due to an insufficient number of tests conducted to achieve a statistically correct distribution. If there is only one test result available, it is not possible to calculate the standard deviation. The standard deviation is a measure of the spread of data, but to calculate it, multiple observations are required. With only a single measurement, there is no basis to assess the variability of the data, and therefore, a standard deviation cannot be determined. The concept of the standard deviation implies a set of data to measure variability.

To determine a conservative calculated value, we assumed a coefficient of variation of 10%.

6 Bearing responds

6.1 Maximum strength anchor plate type 1 - softwood

Sheet pile first failure due to anchor loading

Sample	Force (kN)
Anchor type 1 - soft wood filler whaler	40.0
Average (kN)	40.0
Coefficient of variation (%)	10.00
K	1.65
kn	2.33
n	1.00
Fzt,1,Rk (kN)	30.7

Table 6-1: *1st* Failure anchor type 1 - soft wood filler

6.2 First failure anchor plate type 2 - softwood

Sheet pile first failure due to anchor loading

Sample	Force (kN)
Anchor type 2 - soft wood filler whaler	61.7
Average (kN)	61.7
Coefficient of variation (%)	10
K	1.65
kn	2.33
n	1
Fzt,1,Rk (kN)	47.4

Table 6-2: *1st* Failure anchor type 2 - soft wood filler

6.3 Maximum strength anchor plate type 2 - softwood

Sheet pile total failure due to anchor loading

Sample	Force (kN)
Anchor type 2 - soft wood filler whaler	93.6
Average (kN)	93.6
Coefficient of variation (%)	10
K	1.65
kn	2.33
n	1
Fzt,1,Rk (kN)	71.8

Table 6-3:total Failure anchor type 2 - soft wood filler

6.4 Maximum strength anchor plate type 2 - steel filler

Sheet pile first failure due to anchor loading	
Sample	**Force (kN)**
Anchor type 2 - steel plate filler whaler	92.0
Average (kN)	92.0
Coefficient of variation (%)	10
K	1.65
kn	2.33
n	1
Fzt,1,Rk (kN)	70.6

Table 6-4: total Failure anchor type 2 - soft wood filler

6.5 Failure mode

The three setups yield different failure modes. Based on the results, it is evident that anchor type 1 has an anchor plate that is too narrow. This anchor plate is mounted on the belly of the sheet pile and ends before the flanges begin. This anchor plate essentially eats its way through the composite material. As a result, multiple failure stages are observed, along with significant displacements.

Anchor type 2 spans across the belly of the sheet pile, primarily transferring its load through the flanges. This places the flanges under compression, eventually causing them to buckle. In the version with softwood fillers, the 0/90-degree layer first tears on one side, and then the force rebuilds until the flange buckles on the opposite side.

Figure 6-2 illustrates the various stages of failure.

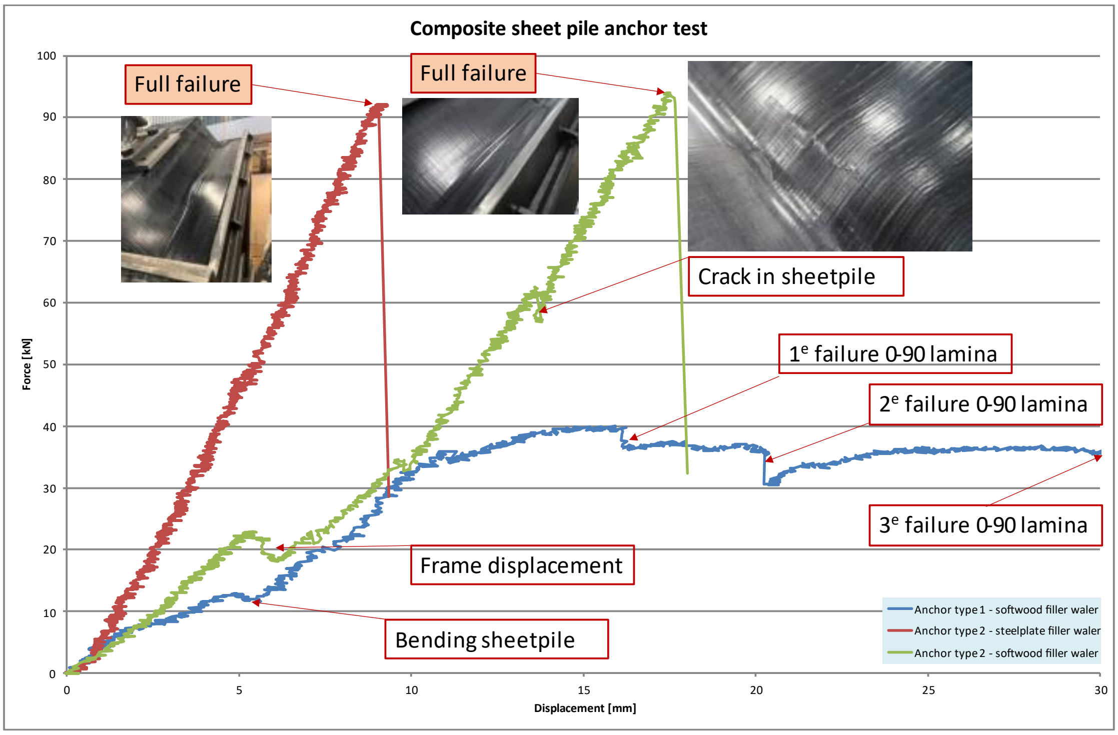


Figure 6-1 Failure modes

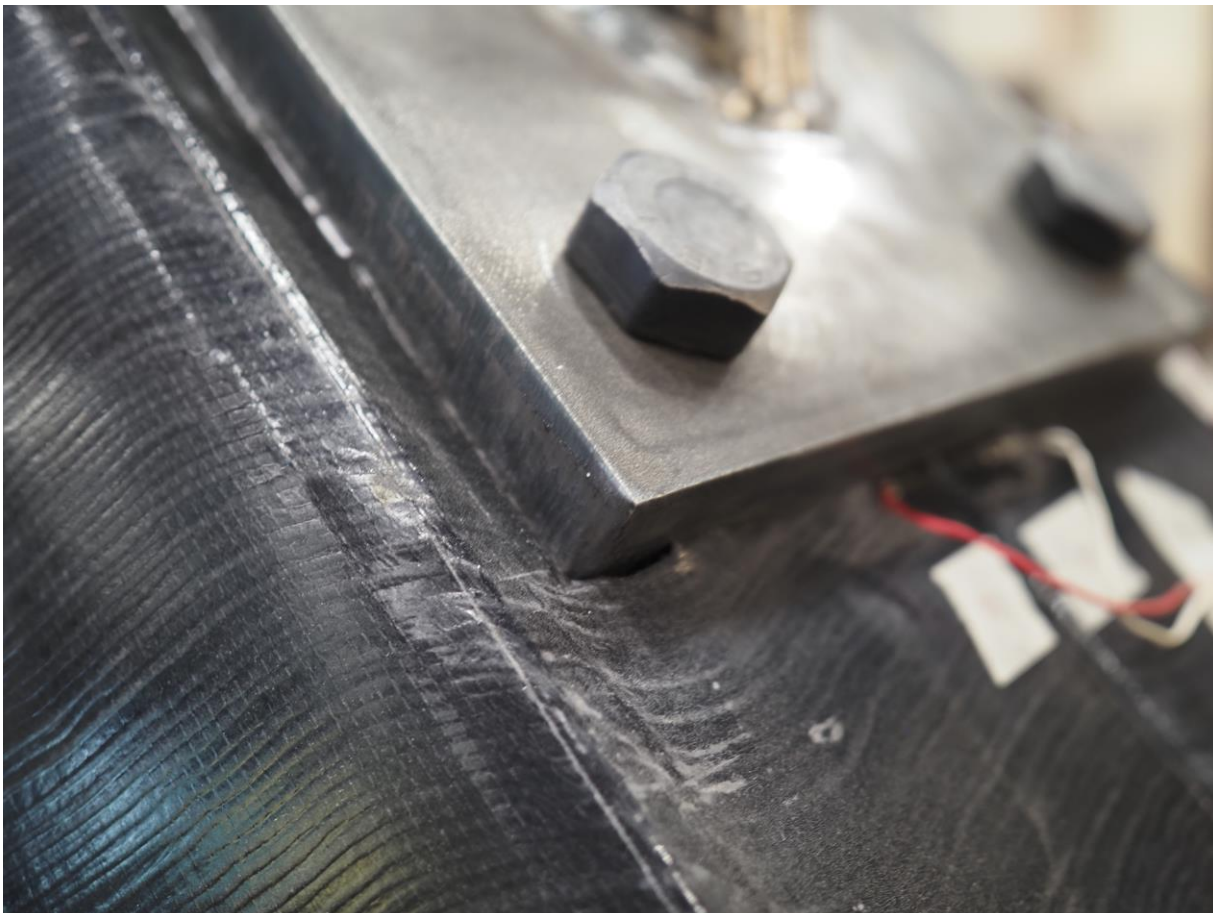


Figure 6-2 First Failure anchor type 1 - soft wood filler plate

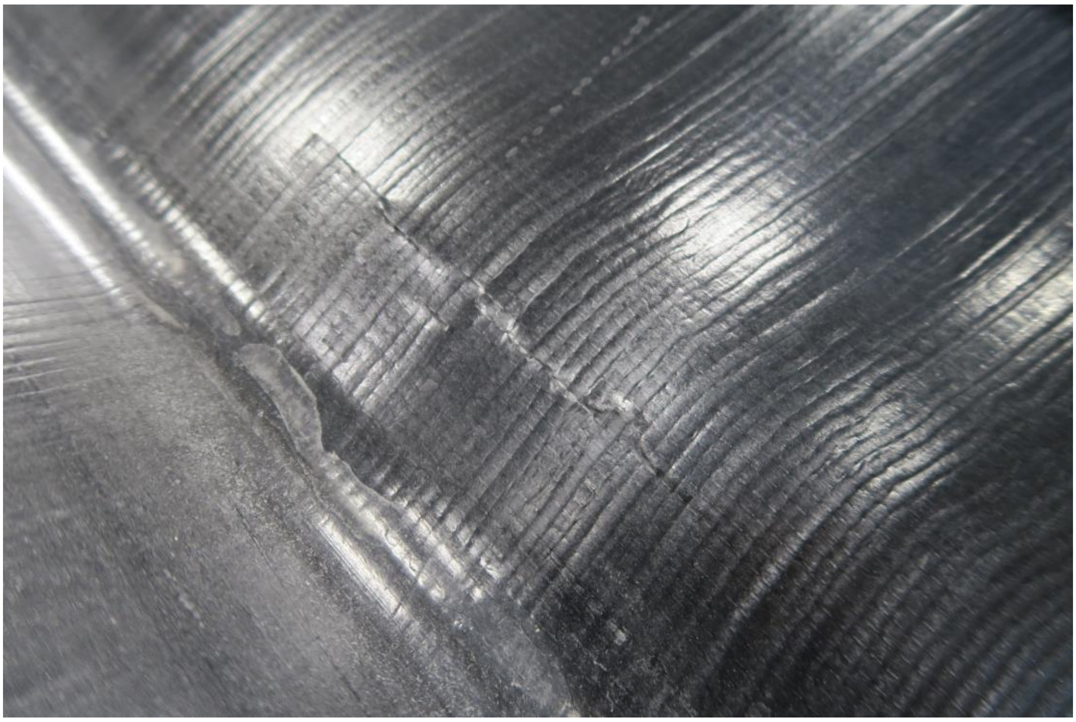


Figure 6-3 First Failure anchor type 2 - soft wood filler plate

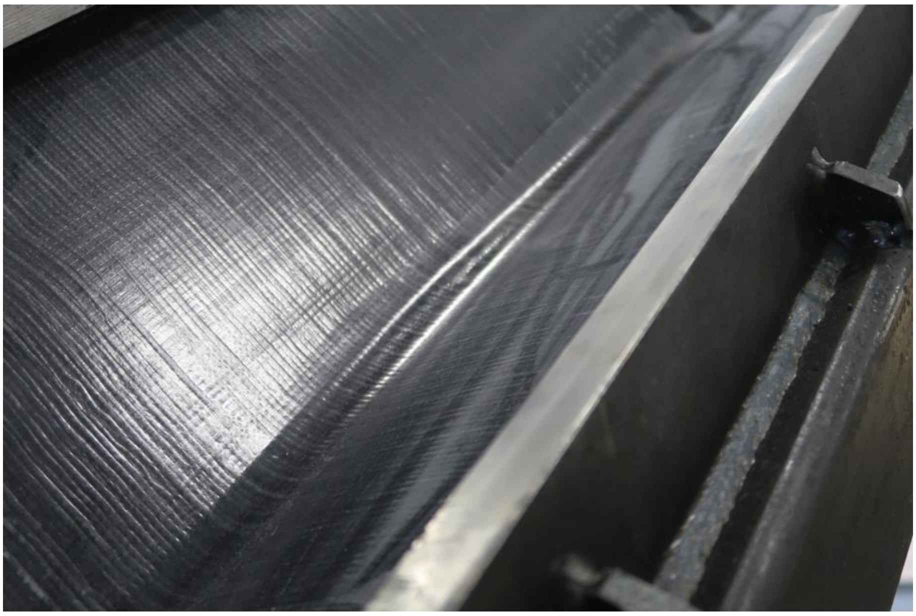


Figure 6-4 Total Failure anchor type 2 - soft wood filler plate

Figure 6-5 Failure anchor type 2 - steel filler plate

7 Summary

The ultimate failure loads and failure type is presented in Table 7-1. The Web buckling capacity - 203.2 mm waler front side - backside fully supported - 90 degree anchor is determined by the Creative composite group themselves, see appendix 8.2. If we compare the results where local buckling occurred than it can be concluded that they are all in the same range.

Test	Max. Failure load (kN)	Max. Failure load (kN/m)(2)	Fzt,1,Rk (kN)	Fzt,1,Rk (kN/m)(2)	Failure type
Web buckling capacity - 203.2 mm (8'') waler front side - backside fully supported - 90 degree anchor	94.3	103.1	83.4	91.2	local buckling
Anchor plate type 1 (300x300) with softwood filler plates in between sheet pile and wale beam (100 mm)	40	43.7	30.7(1)	33.6(1)	Punching shear
Anchor plate type 2 (300x300 + fill plate overlapping the belly of the sheet pile) with softwood filler plates in between sheet pile and wale beam (100 mm)	61.7 / 96.6	67.5 / 102.4	47.4(1) / 70.6(1)	51.8(1) / 77.2(1)	local buckling
Anchor plate type 2 (300x300 + fill plate overlapping the belly of the sheet pile) with steel filler plates in between sheet pile and wale beam (100 mm)	93.6	102.4	71.81)	78.51)	local buckling

(1) Estimated with a coefficient of variation of 10%

(2) sheet pile width is 0.9144 m

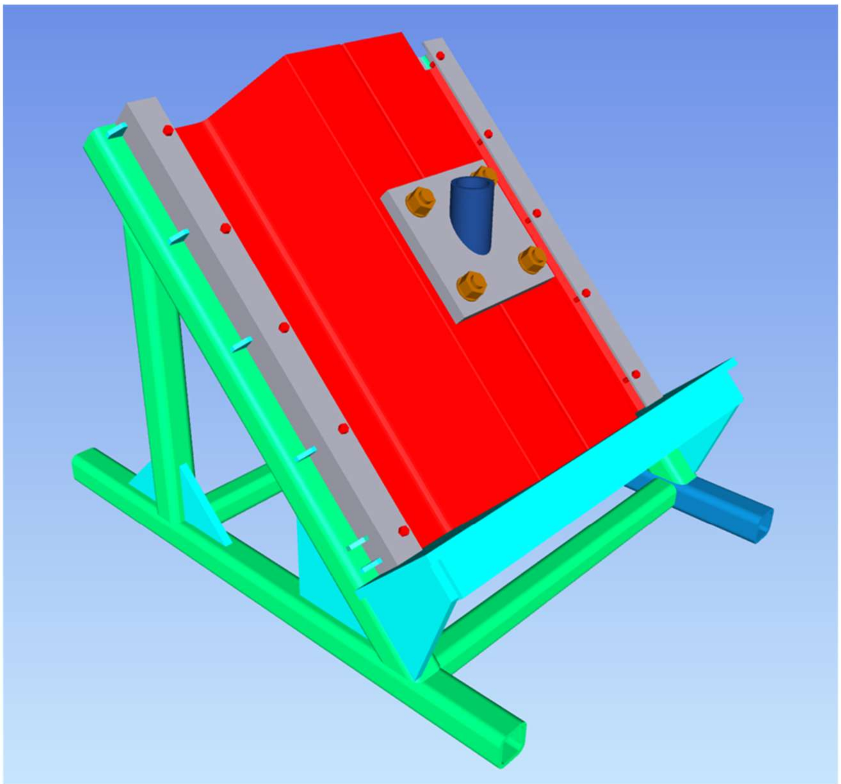
table 7-1 Failure loads according to full scale lab. tests

8 Appendix

8.1 Appendix A – Report Anchor frame

Design Anchorframe

-



Projectnaam: Opwaardering Twentekanalen
Opdrachtgever: Rijkswaterstaat GPO
Opdrachtnemer: Combinatie Van Oord, Hakkers, Beens
Onderaannemer: Witteveen+Bos, TU/e, Dept. of Built Environment

Status: Definitief
Revisie: 1.0 – 28-02-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0	Prepared by		OLDN	28-02-2023
	Checked by		CLAW	28-02-2023
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0	28-02-2023	Final Version

Table of content

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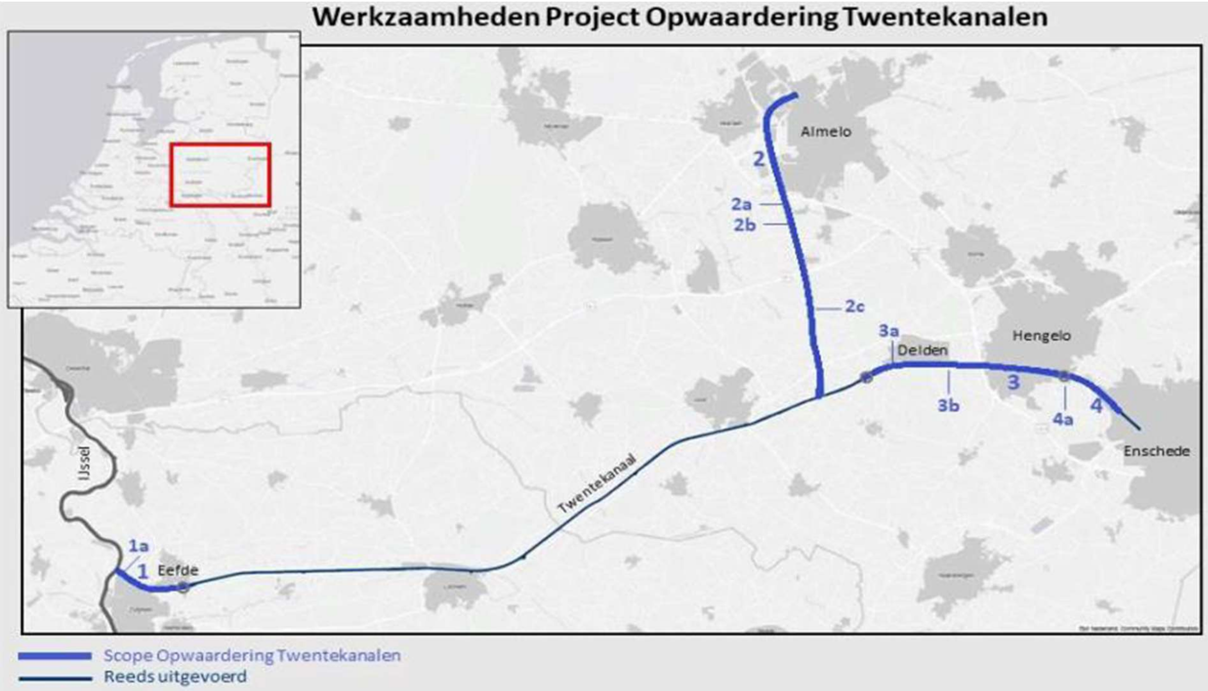


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometer points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

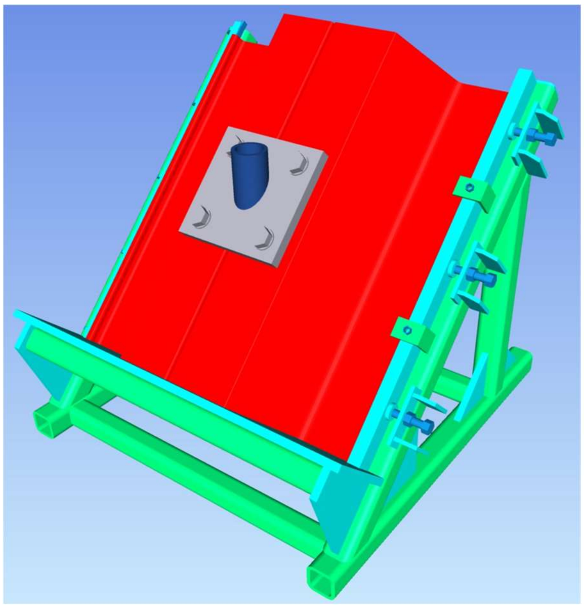
1.2 Goal of this document

In order to implement composite sheet piles on a large scale in the Netherlands, it is crucial to adapt these sheet piles to the specific soil conditions prevalent in the country. In Dutch construction practices, steel sheet piles with grout anchors are commonly utilized. The grout anchor is inserted into the ground at an angle and tensioned against an anchor plate mounted on the sheet pile or the wale. Composite sheet piles must demonstrate the capability to withstand comparable anchor forces as possible on steel sheet piles.

Typically composite sheet piles are equipped with low-capacity anchors due to limited force transmission with the composite material. The commonly used self-drilling anchors in the Netherlands are efficient in that they can withstand high forces and can be implemented with minimal environmental impact. The combination of high anchor forces and composite sheet piles has never been attempted before. This implies that the composite sheet pile will be subjected to a loading condition that has not been tested previously, and the actual capacity of the composite sheet pile under such loading is uncertain.

To assess the capacity of composite sheet piles under anchor loading, a test setup has been established using a steel anchor frame set at a 45-degree angle. This report outlines the calculations for the steel anchor frame, which are based on a conservatively estimated maximum allowable anchor force.

Laboratory tests will be conducted to gain insight into local failure mechanisms, especially buckling. This report presents the calculation of the test frame used for conducting tests on the sheet piles. Figure 1.1 depicts the test frame with the sheet pile.



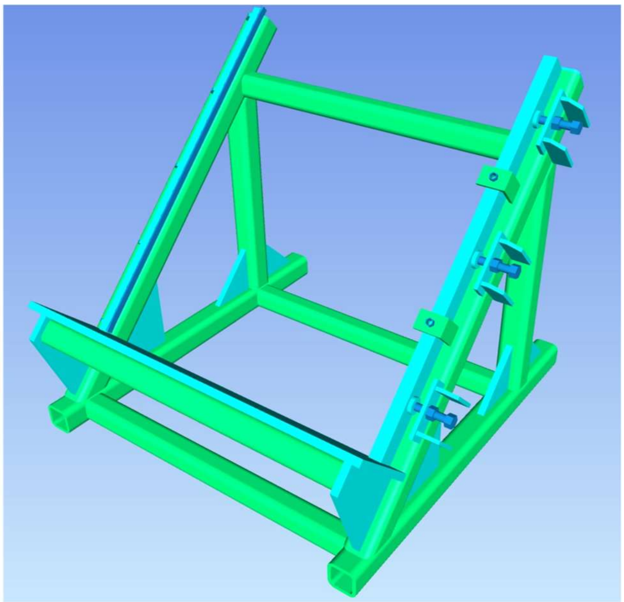


Figure 1-3 Test frame (in- and excluding the sheetpiles in red)

1.3 References

The following standards and guidelines have been applied

Tabel 1-1: Reference Documents Eurocode

Reference	Code	Titel
[Ref.1]	NEN-EN-1990-A1/NB	Grondslagen voor constructief ontwerpen
[Ref.2]	NEN-EN-1991-1-1/NB	Belastingen op constructies - Algemene belastingen
[Ref.3]	NEN-EN-1993-1-1/NB	Ontwerp en berekening van staalconstructies - Algemene regels en regels voor gebouwen

Tabel 1-2: Referentie Tekeningen

Reference	Number	Titel
[Ref.4]	v2 incl ankerstoel	Testframe damwanden

2 Design Basis

2.1 Materials

For the calculation, the following material properties are considered:

- Steel test frame: S355;
- Sheetpile: FRP;
- Bols: 8.8 quality.

Table 2-1: Material Properties

Properties		**S355**
Minimum Yield Strength	t ≤ 40mm	355 N/mm2
	40 < t ≤ 80mm	335 N/mm2
Tensile Strength	t ≤ 40mm	490 N/mm2
	40 < t ≤ 80mm	470 N/mm2
Coefficient of Thermal Expansion		12·10-6 K-1
Elastic Modulus		210.000 N/mm2
Shear Modulus		81.000 N/mm2
Poisson's Ratio		0,3
Specific Weight		78,5 kN/m3

3 Geometry and Modeling

3.1 Geometry

The geometry of the test frame, including the sheet pile, is depicted in Figure 3.1.

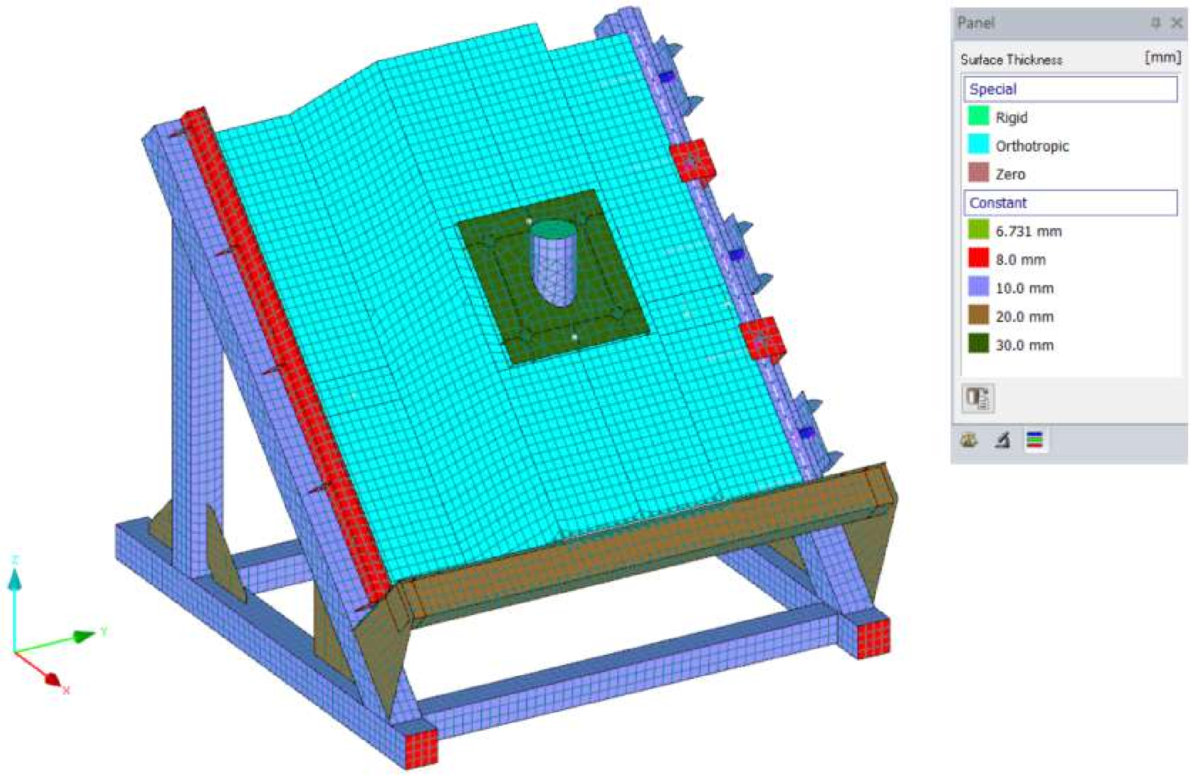


Figure 3-1 Geometry of the test frame including the sheet pile

Three modifications have been made compared to the model in [Ref.4]. These adjustments are illustrated in Figure 3.2 through Figure 3.4. Firstly, an additional crossbar (80x80x10) has been added to the frame to limit the deflection of the sheet pile, as shown in Figure 3.2.

Secondly, the sketch plates at the bottom of the support plate have been moved outward to align with the wall of the box, as seen in Figure 3.3. Lastly, the box 80x80x10 beneath the support plate has been replaced by three plates of 20mm, as depicted in Figure 3.4.

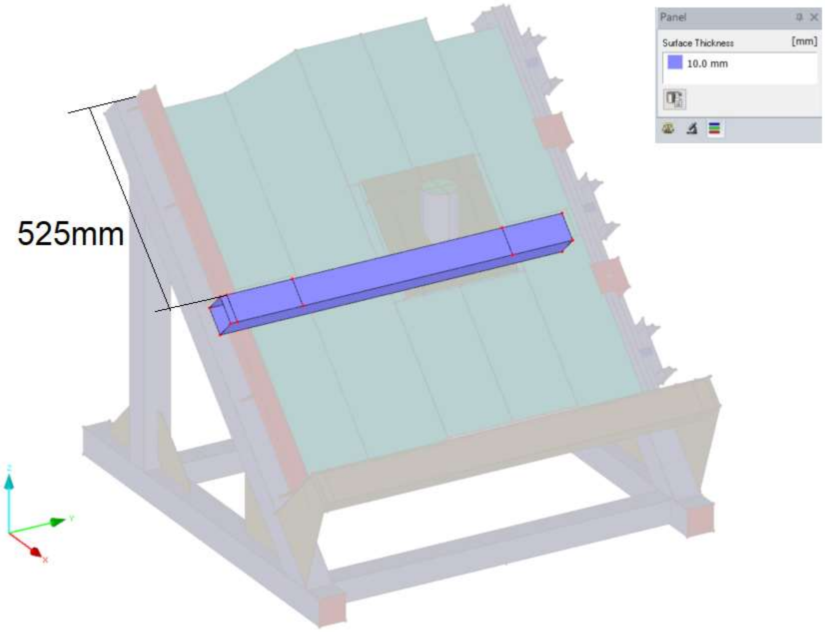


Figure 3-2 Extra wale beam

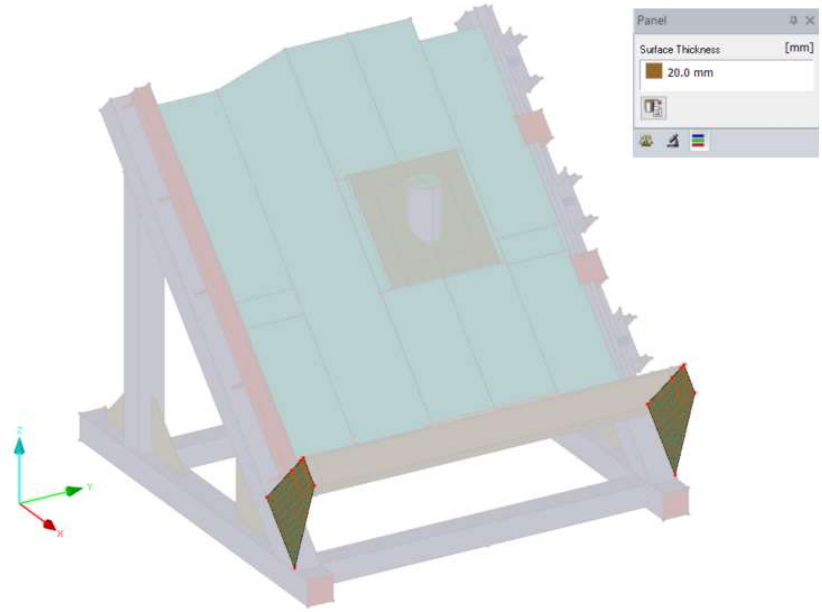


Figure 3-3 Moved sketched plates

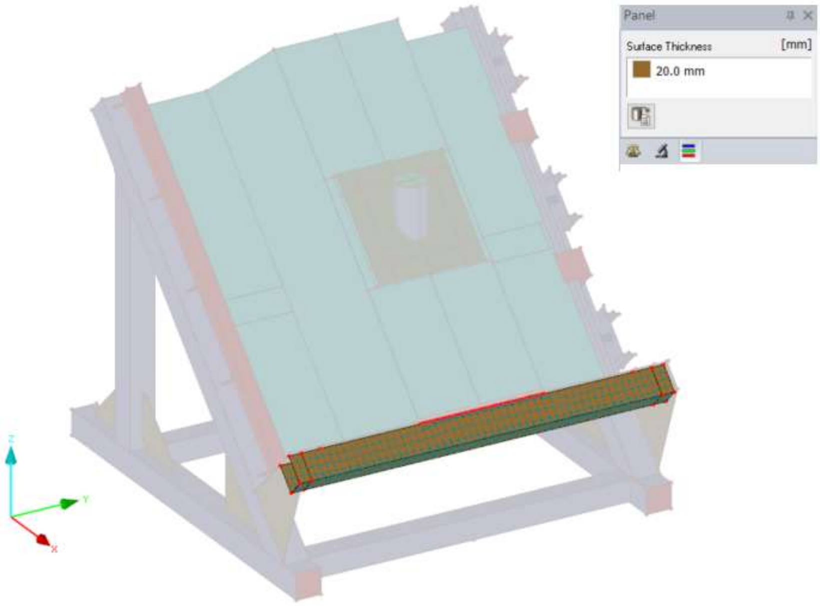


Figure 3-4 Replacement of boxgirder by plates t=20

3.2 Modeling

For the modeling, the finite element program RFEM5 is utilized. In this program, the components are modeled using 1D beam elements or 2D plate elements. The 2D plate elements are automatically generated with an intended mesh size of 20 millimeters. The structural model is geometrically non-linearly analyzed due to the application of nonlinear boundary conditions (support only under compression). The direct method for solving the system of equations is employed. The Mindlin plate bending theory is used for plate elements.

The sheet pile is simplistically modeled since we are not conducting a verification of the sheet pile. The sheet pile is solely used to transmit forces correctly to the test frame.

3.3 Loads

For the design of the steel structure, considerations include the self-weight of the frame and the test load. This test load is set at 100 kN. As an additional check, the frame has also been analyzed with a maximum test load of 200 kN.

4 Structural Implementation

4.1 Cross-Section Classification

The steel profiles must be classified in accordance with NEN EN 1993-1-1. The cross-section classification for each component is presented in Table 4.1. For the construction, all components fall into section class 1, making them not prone to buckling.

Tabel 4-1: Doorsnedeklasse

Component		f_{yk} $[N/mm^2]$	ϵ [-]	c [mm]	t [mm]	c/t [-]	Class 1	Class 2	Class 3	Class 4
SHS	70x10	355	0,81	30	10	3	**≤26,7**	≤30,8	≤34,0	≥34,0
SHS	80x10	355	0,81	40	10	4	**≤26,7**	≤30,8	≤34,0	≥34,0

4.2 Ultimate Limit State

The maximum stress in the steel structure is calculated using the finite element program. The results are shown in Figure 4.1 through Figure 4.6.

In Figure 4.1, the result for the test load of 100 kN is displayed. The maximum stress is equal to 419 MPa, which exceeds the allowable 355 MPa. However, this value represents a very localized peak stress and can be neglected for this reason, as shown in Figure 4.2. The maximum stress in the model without this peak stress is 340 MPa, which is below the allowable 355 MPa.

Afbeelding 4.1: LC1 100[kN] proefbelasting

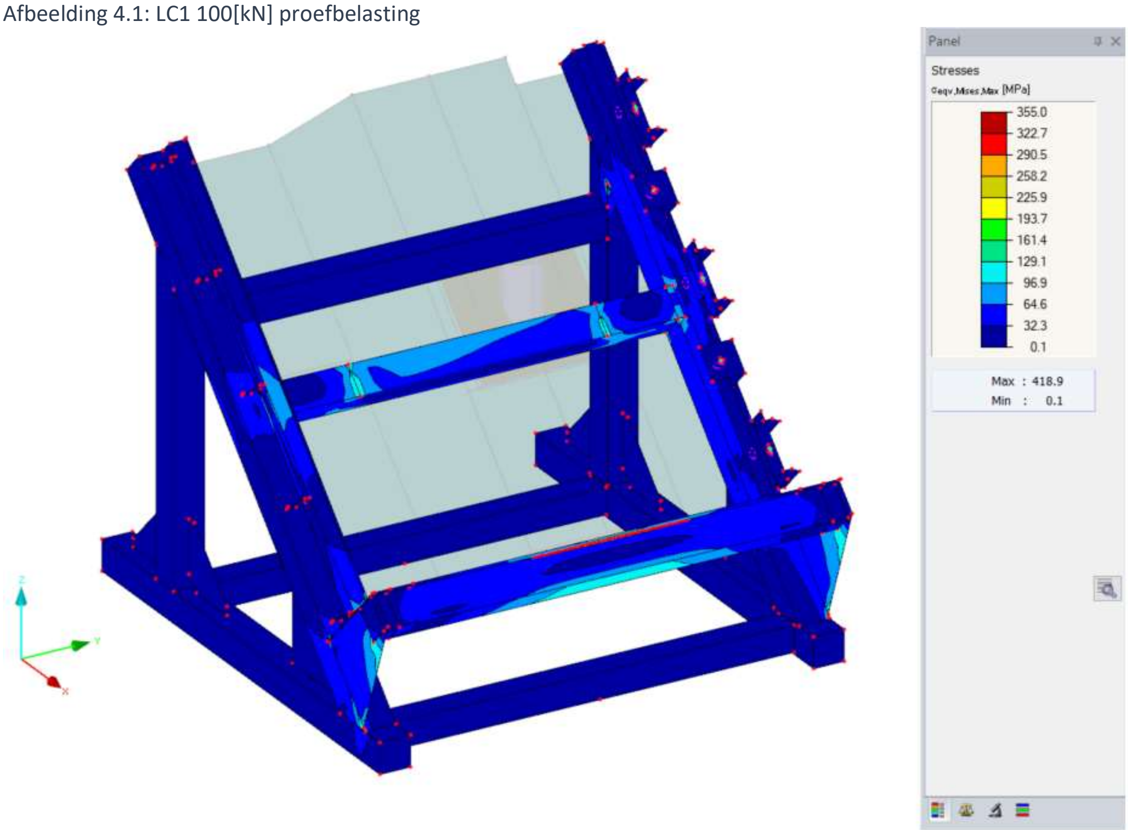


Figure 4-1 LC1 100[kN] test load

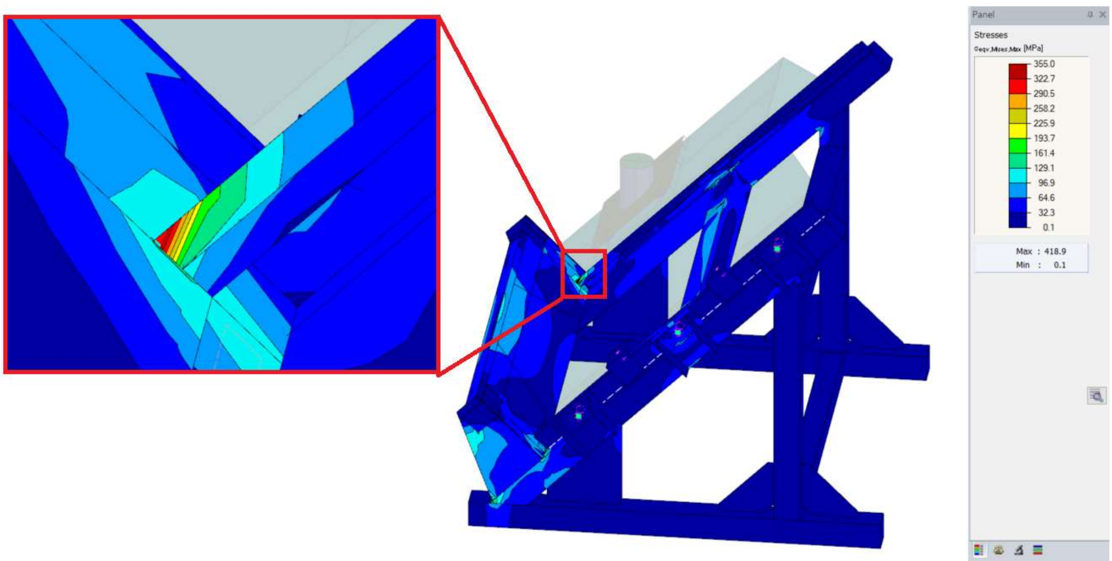


Figure 4-2 Peak stresses

In Figure 4.3, the result for the maximum test load of 200 kN is shown. The maximum stress is 834 MPa, significantly exceeding the allowable 355 MPa. However, these are also very localized peak stresses, as indicated in Figure 4.4 and Figure 4.5. Given the location and magnitude of the exceedance, these values can be considered as peak stresses.

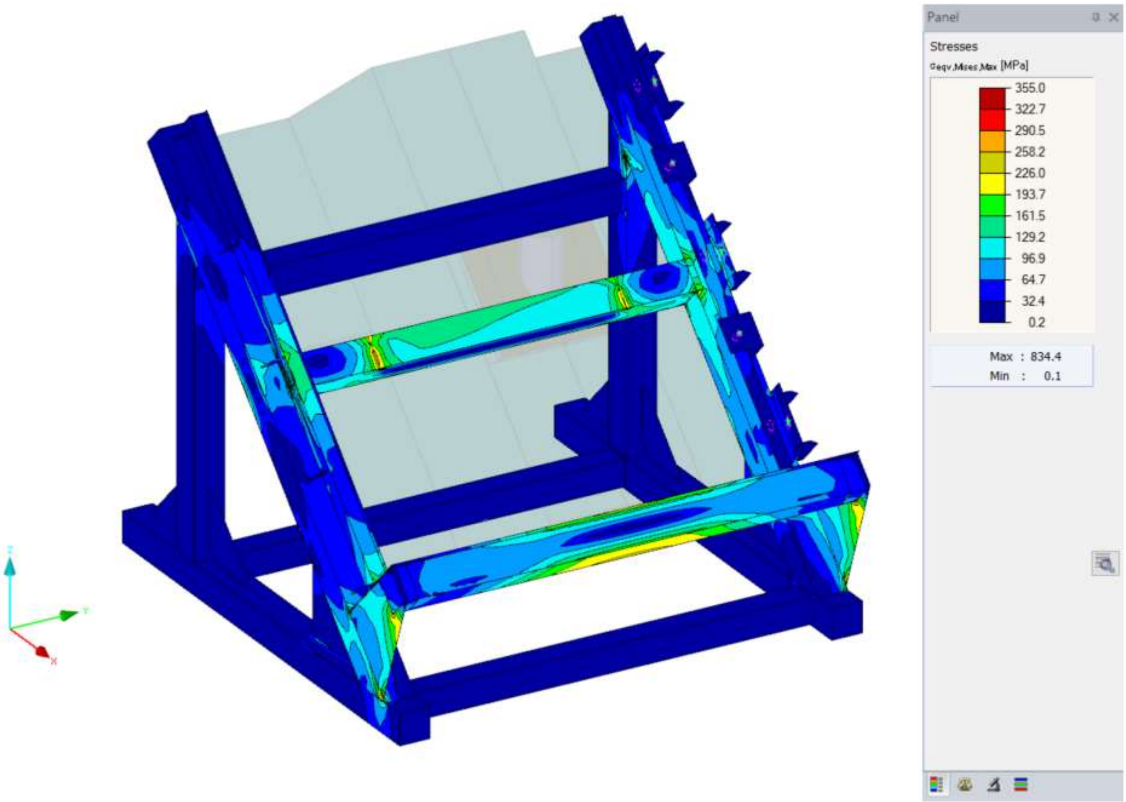


Figure 4-3 LC2 200[kN] Maximum test load

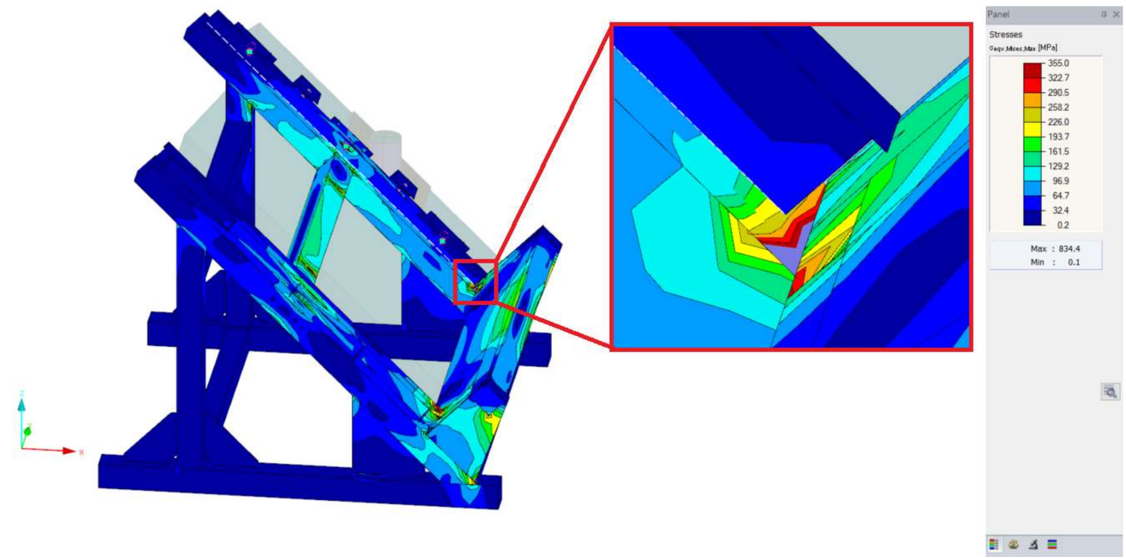


Figure 4-4 Location 1 peak stresses

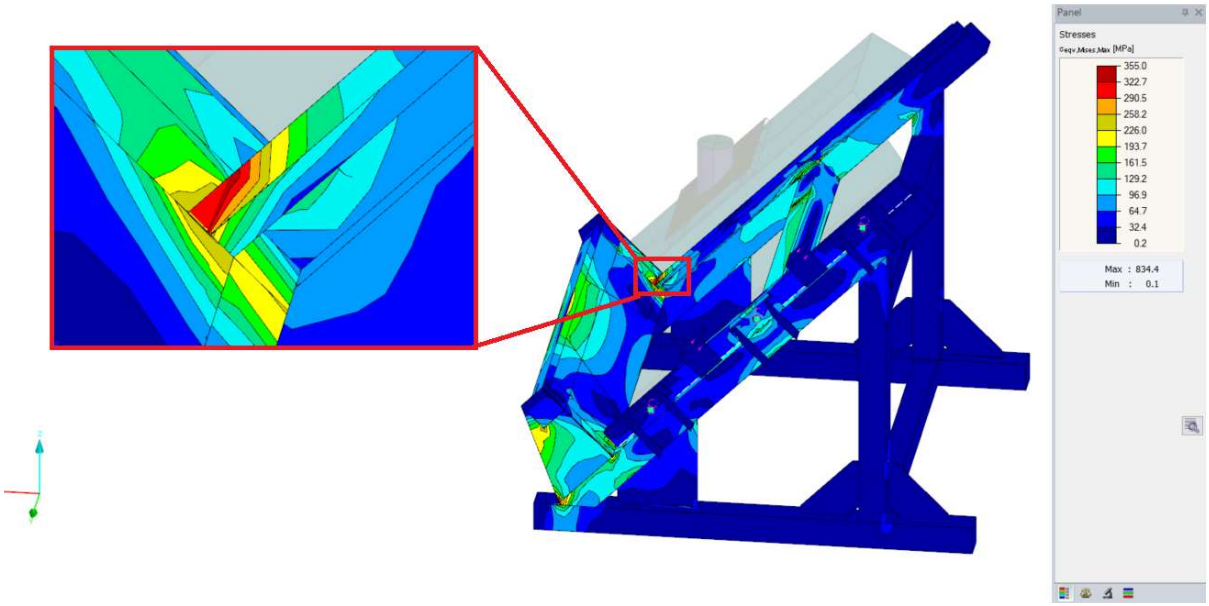


Figure 4-5 Location 2 peak stresses

When the peak stresses are not taken into account, we find a maximum stress of 342 MPa in the test frame, as shown in Figure 4.6. This is still below the permissible maximum stress of 355 MPa.

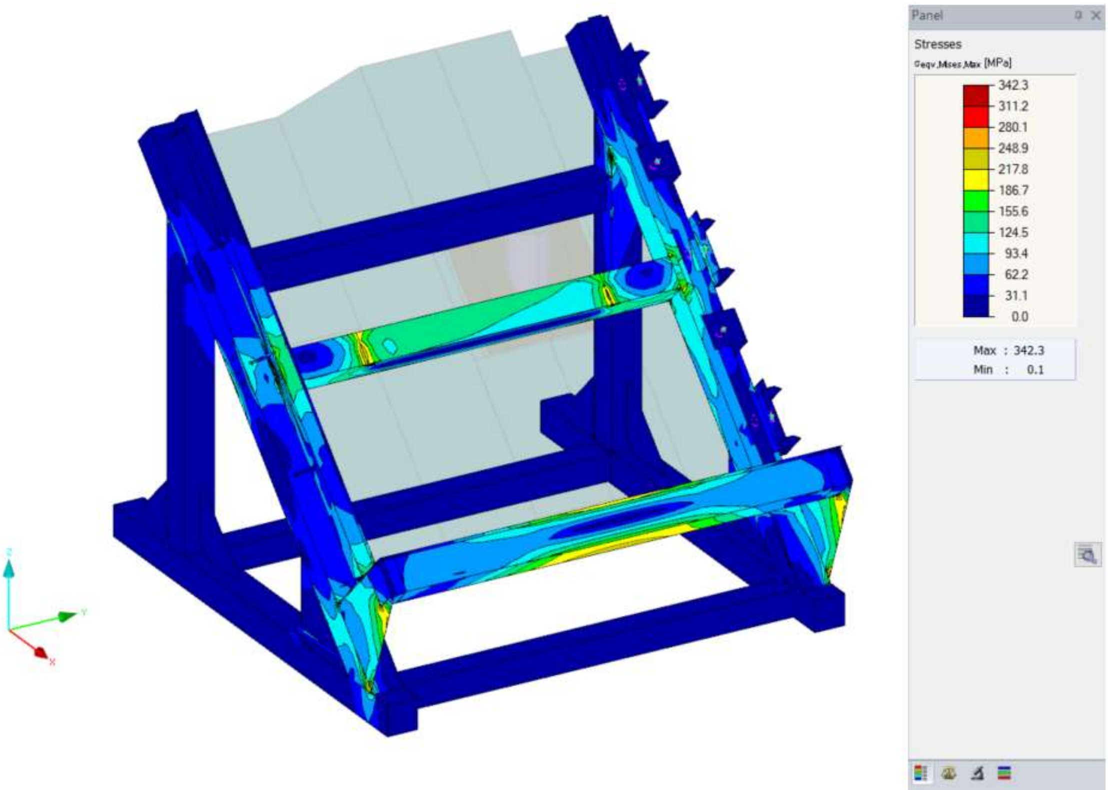


Figure 4-6 Maximum stress without peak stresses

5 Conclusion

Based on the calculations, it can be concluded that the test frame can be safely used for the test load of 100 kN. The additional calculation also reveals that the test load can be increased to a maximum of 200 kN, and at this load, the steel frame still meets the required criteria.

8.2 Appendix B – Web buckling test

Creative Pultrusions, Inc
214 Industrial Lane
Alum Bank, PA 15521
(814) 839-4186
www.creativepultrusions.com

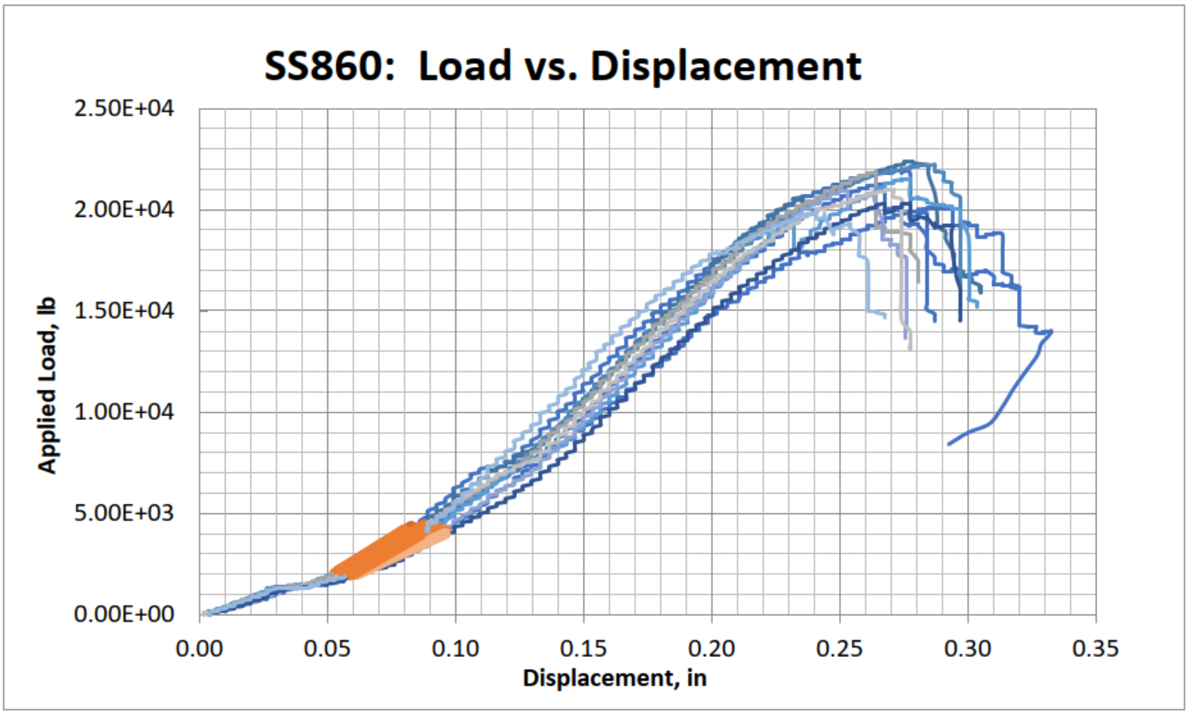
Creative Pultrusions Test Report

Report Name:SS860 Full Section Testing
Test Date: 08-16-2022
Part Tested: SS860
Part Manufactured Date: NA
Performed By: S. Felix & T. Crouse

Test Description: A web buckling test was conducted to determine the characteristic values to use in the sheet pile brochure tables. The test was conducted by using a 2" steel bar, 8" wide steel plate and a 48" SS860 sheet pile. The sheet was positioned flat on the 50 kip test machine base and clamped in place with the test fixture. The test fixture and specimen were marked to allow the load cell to be centered on the part for each test. Repetitions of the test were conducted using the same test fixture, steel bar, and plate. The steel bar was used to evenly distribute the load across the steel plate into the sheet.

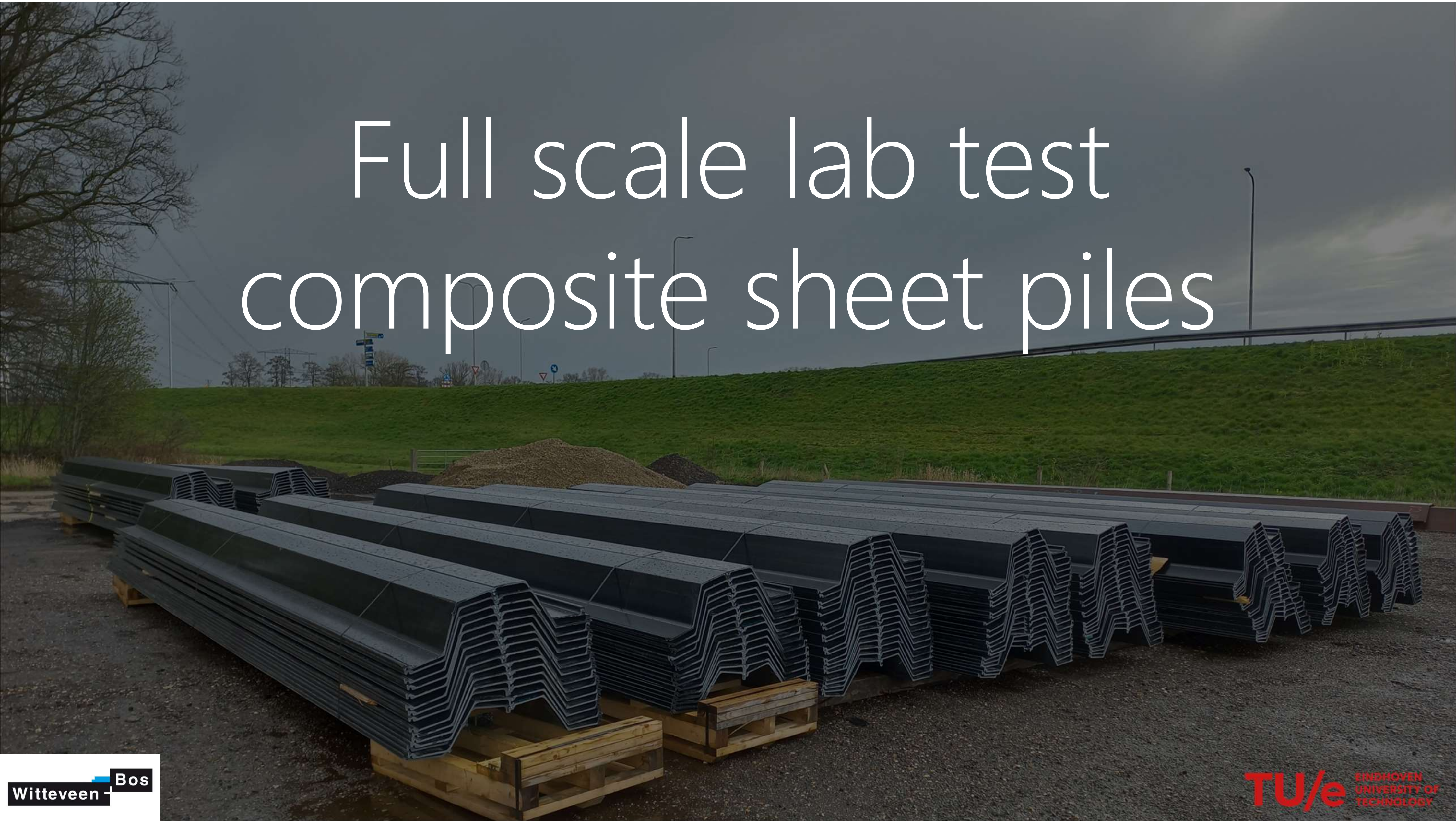
Test Data:

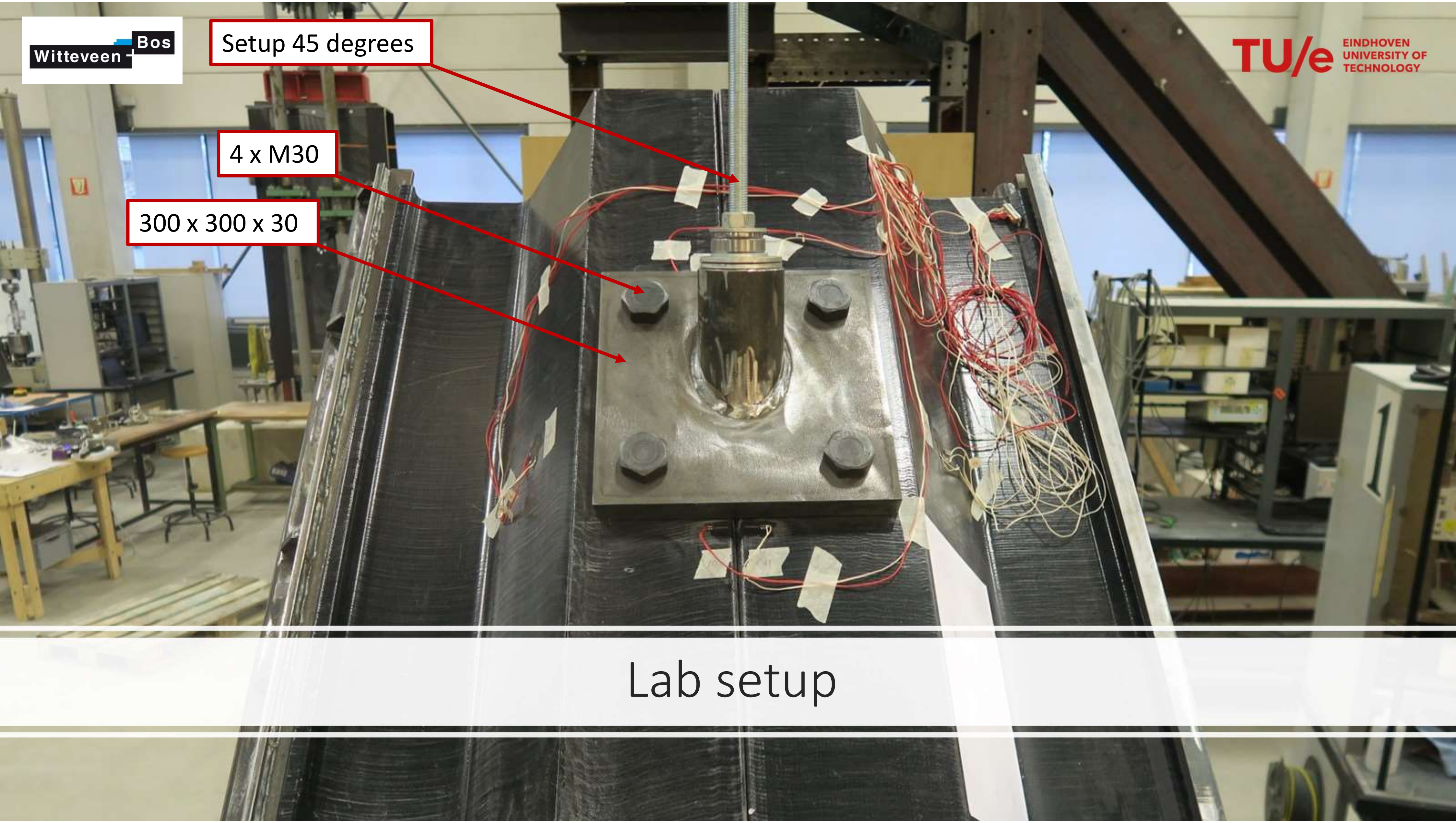
	Peak Load, lbf	Web Buckling Capacity, lbf/ft
# of Specimens:	12	12
Mean Value:	21204	7068
St. Dev.:	826	275
COV:	0.040	0.040
Characteristic value:	18760	6253
	83.4 kN	91.3 kN/m



SS860: Load vs. Displacement
Applied Load, lb
2.50E+04
2.00E+04
1.50E+04
1.00E+04
5.00E+03
0.00E+00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Displacement, in

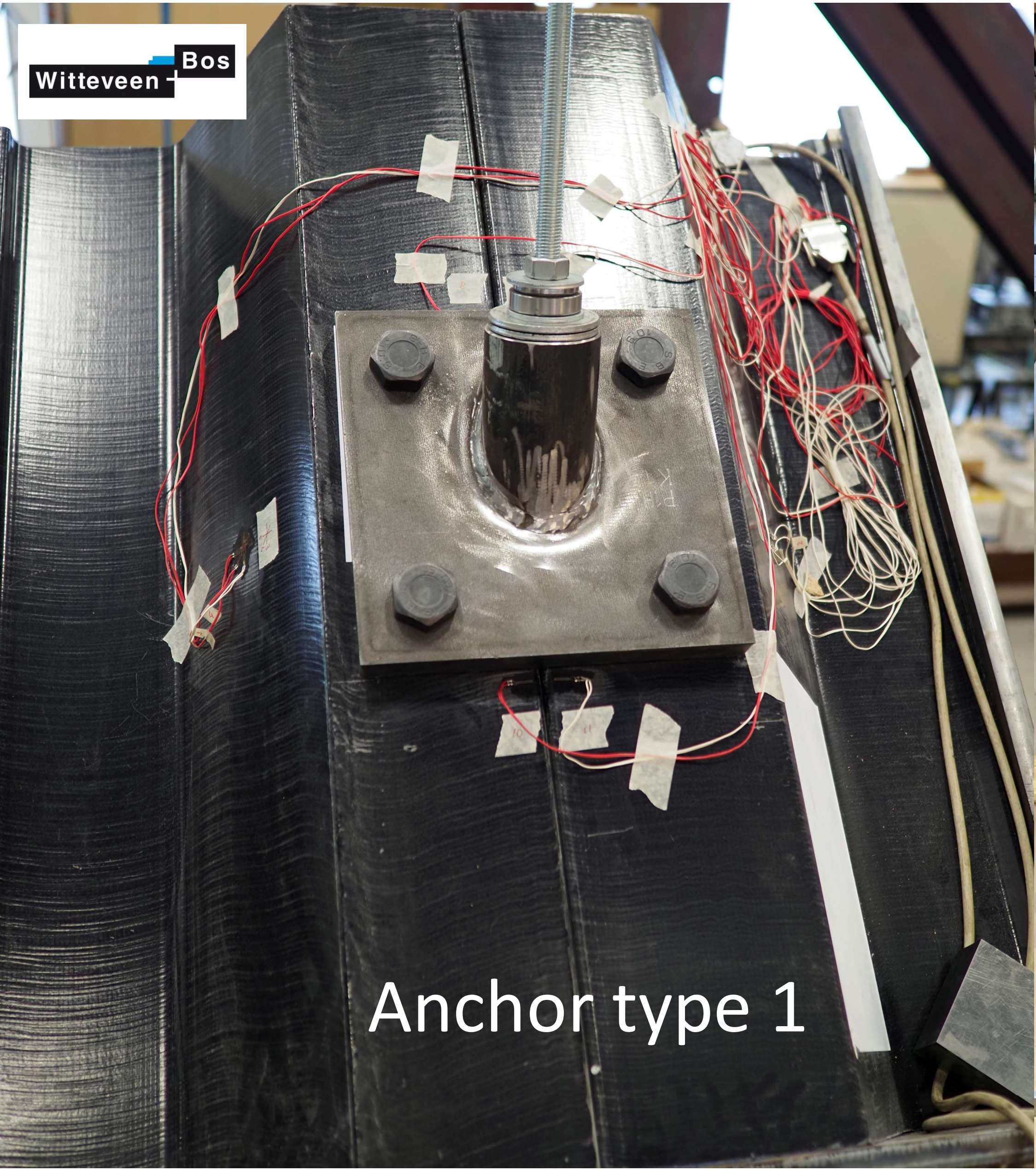
8.3 Appendix C – Presentation results and test

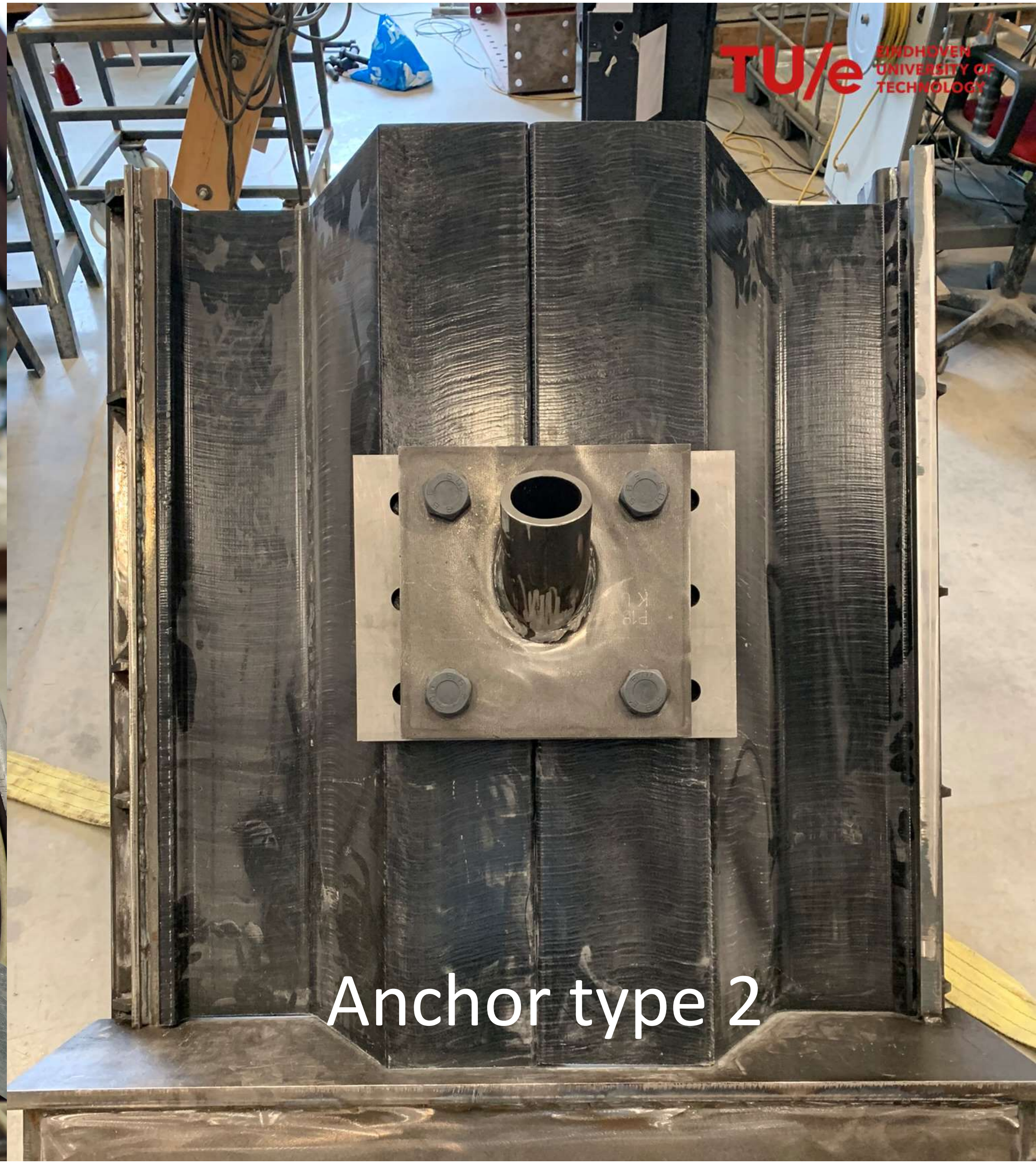
Full scale lab test composite sheet piles





Lab setup


Witteveen + Bos
Anchor type 1

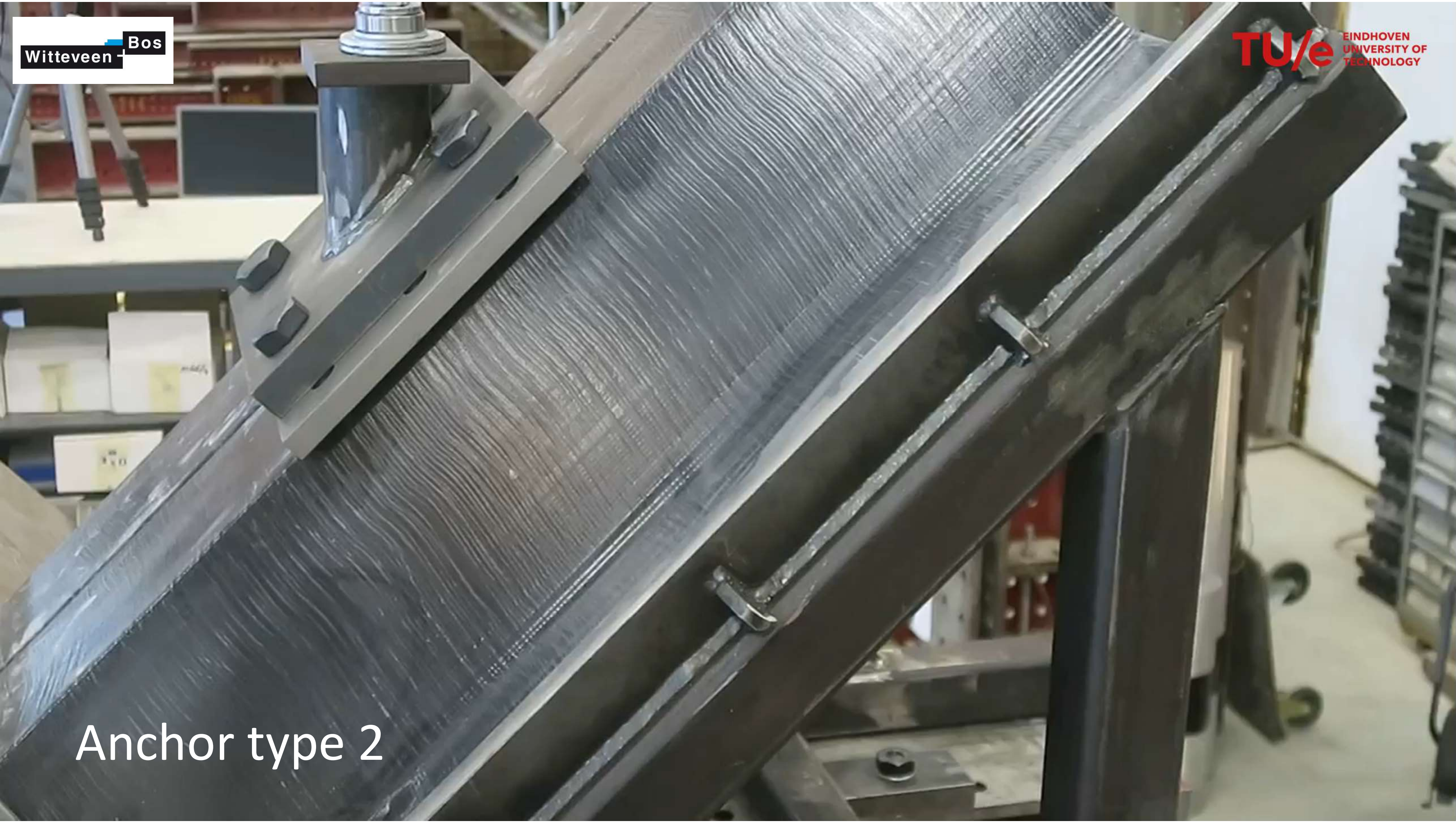

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Anchor type 2

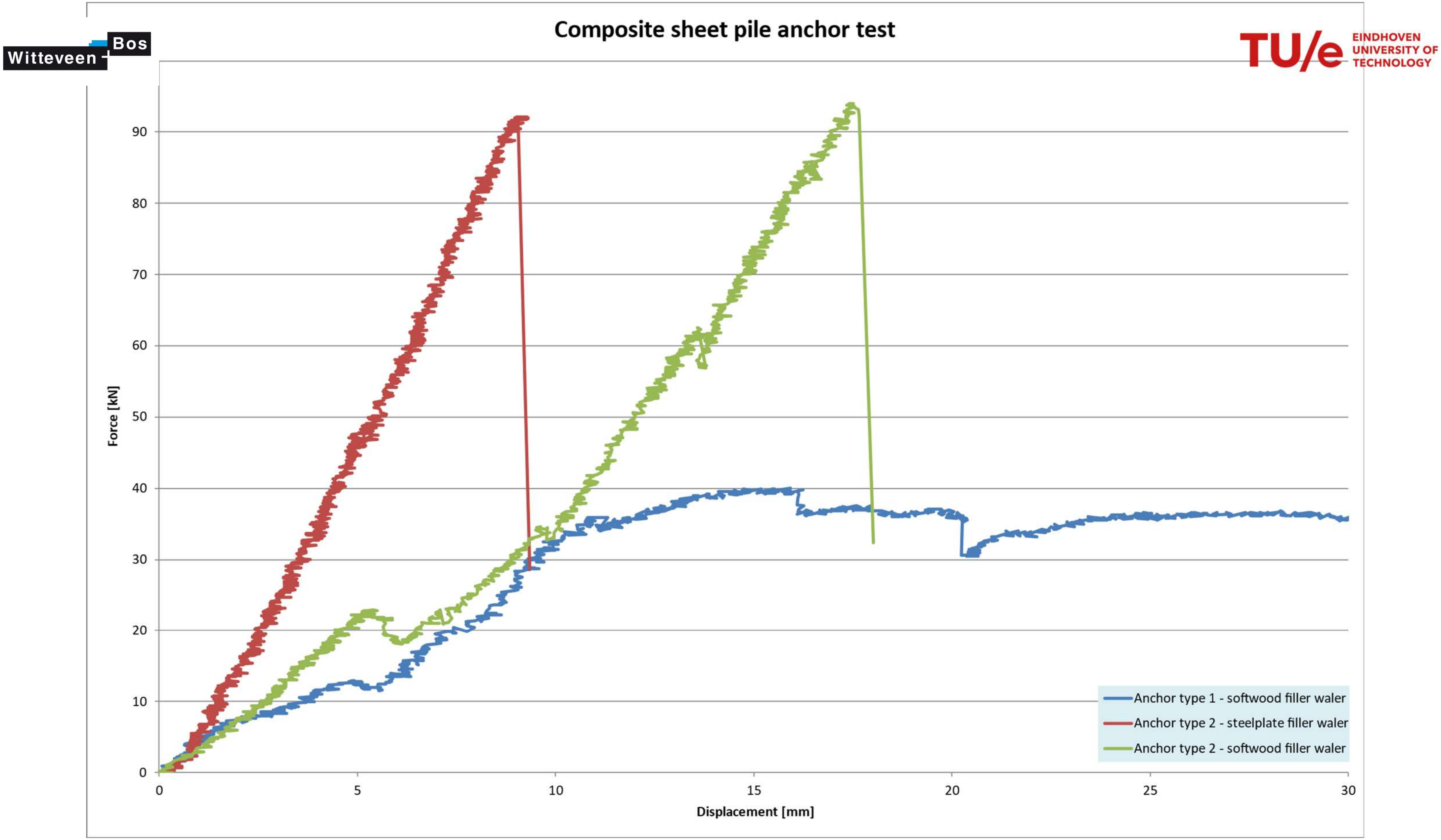
Steel filler

Softwood filler

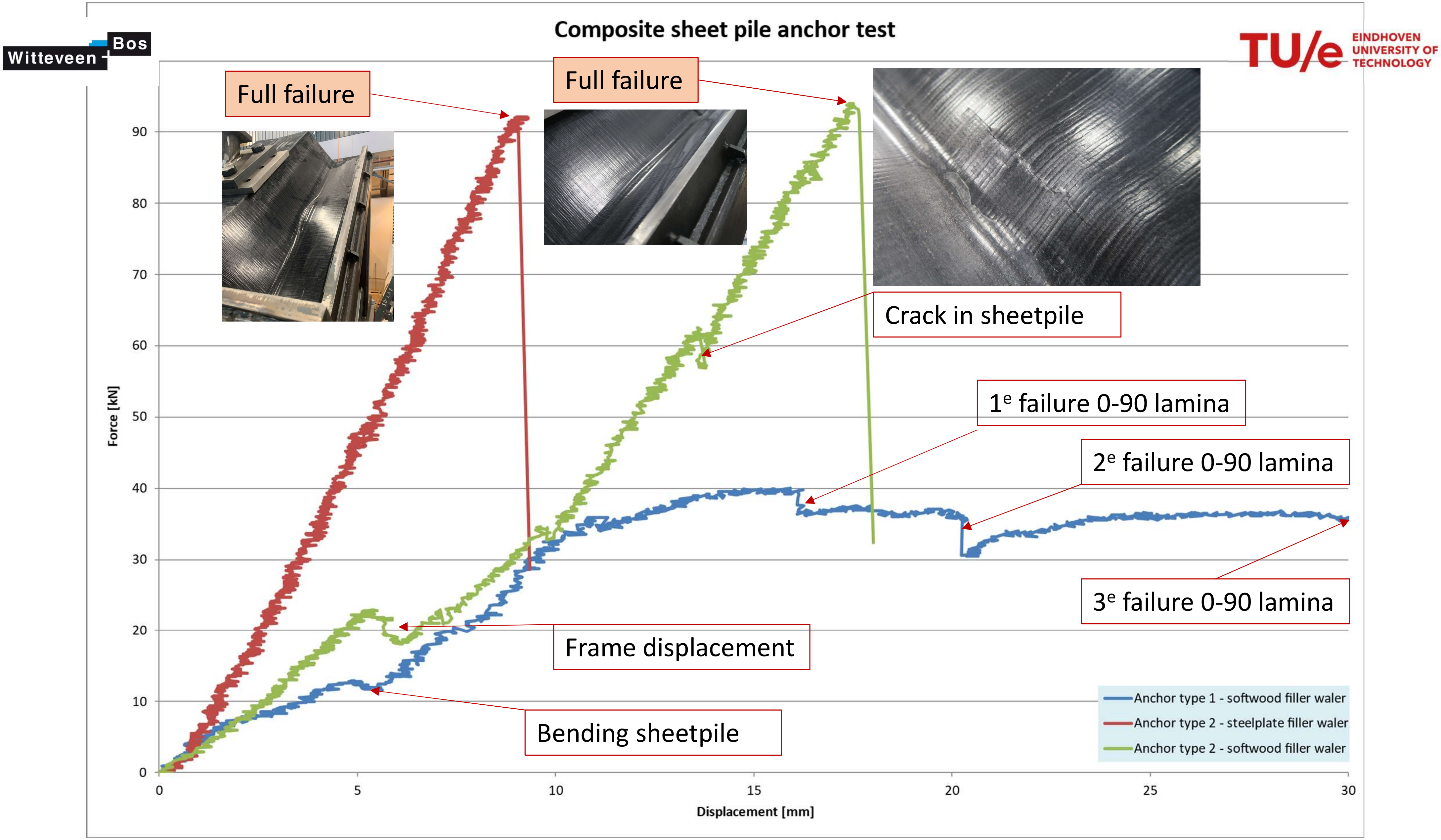
Witteveen + Bos

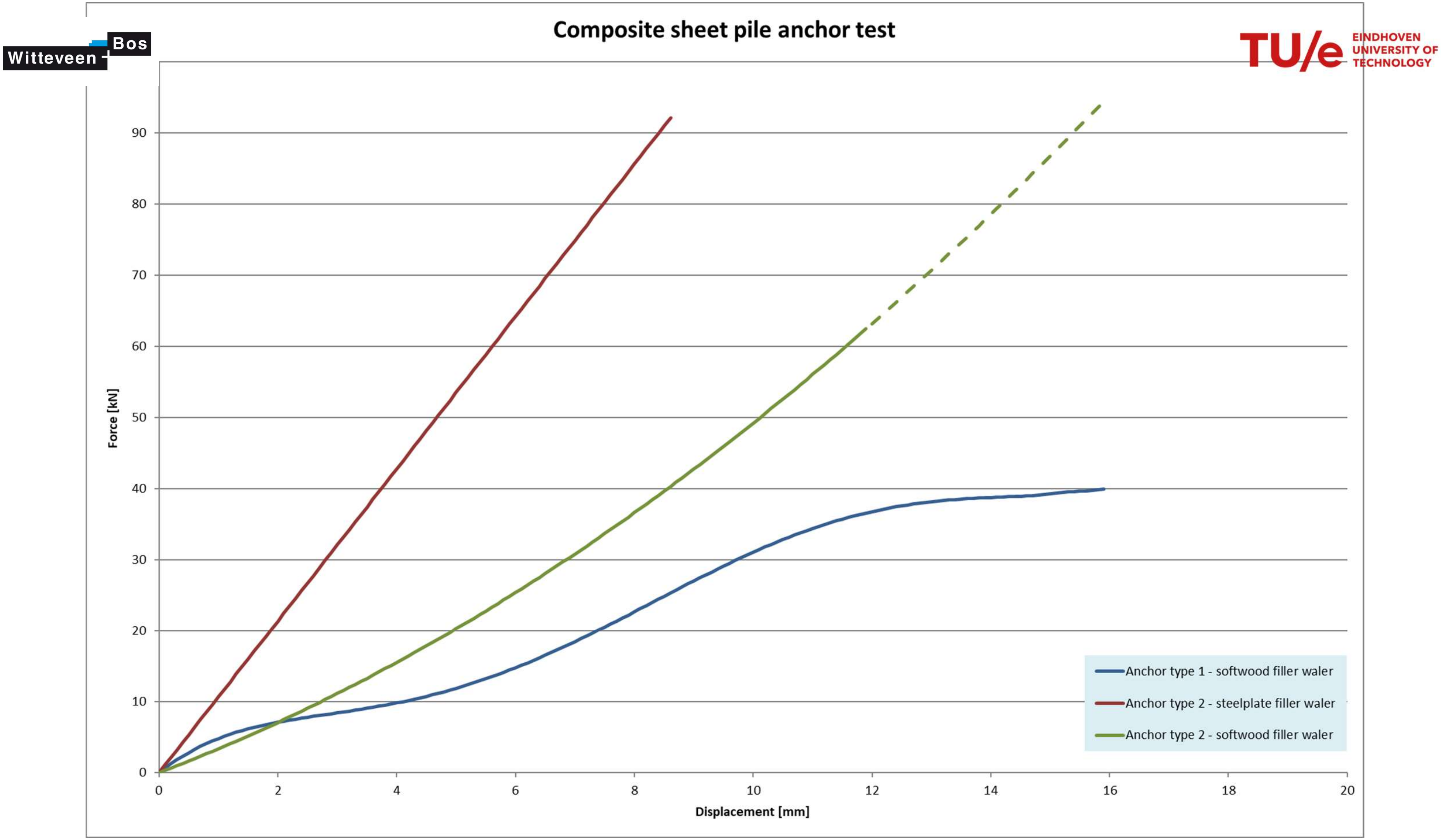
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY


Witteveen + Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Anchor type 2



Composite sheet pile anchor test
Witteveen + Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Force [kN]
0
10
20
30
40
50
60
70
80
90
Displacement [mm]
0
5
10
15
20
25
30
Anchor type 1 - softwood filler waler
Anchor type 2 - steelplate filler waler
Anchor type 2 - softwood filler waler


Composite sheet pile anchor test
Witteveen + Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Full failure
Full failure
Crack in sheetpile
1e failure 0-90 lamina
2e failure 0-90 lamina
3e failure 0-90 lamina
Frame displacement
Bending sheetpile
Force [kN]
Displacement [mm]
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
Anchor type 1 - softwood filler waler
Anchor type 2 - steelplate filler waler
Anchor type 2 - softwood filler waler



Composite sheet pile anchor test
Witteveen + Bos
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Force [kN]
Displacement [mm]
0
10
20
30
40
50
60
70
80
90
0
2
4
6
8
10
12
14
16
18
20
Anchor type 1 - softwood filler waler
Anchor type 2 - steelplate filler waler
Anchor type 2 - softwood filler waler

5.9 Appendix I – Report full scale tests outside

Full-scale tests
Composite sheet piles

-

Project name: Opwaardering Twentekanalen
Client: Rijkswaterstaat GPO
Contractor: Combinatie Van Oord, Hakkers, Beens
Sub-contractor: Witteveen+Bos, TU/e, Dept. of Built Environment

Status: Final
Revision: 1.0 – 13-10-2023

Rev. no.	Verification		Approval	
			Initials	Date
1.0	Prepared by			
	Checked by			
	Lab Technician(s)			

Document History		
Rev.no.	Date	Description
1.0	13-10-2023	Final Version

Test report overview

Customer:	RWS
Part description:	1580 Sheet pile PE resin
Producer:	Creative Composite Group
Country of origin:	United States
Date test 1:	12-06-2023
Date test 2:	13-06-2023
Test standards:	-
Material:	E-glass, polyester
Specimen type:	full scale 7 meter length
Machine:	hydraulic jack
Pre-load:	0 MPa
Test speed:	5 kN/min

Table of content

1 Introduction

1.1 Project description

The Twente Canals are a crucial logistical link for the transportation of goods by water to the ports of Almelo, Hengelo, and Enschede. It is expected that in the coming years, transport via the canal will increase, which is why the canal is being expanded.

Expanding the canal will allow larger and more heavily loaded ships to navigate the Twente Canals faster and safer in the future, making the ports along the canal more accessible. This increased accessibility is both a boost to the regional economy and employment and contributes to strengthening the (inter)national logistical position of the Twente region.

The section between Lock Eefde and beyond Lochem has already been widened and deepened for Class Va/M8 ships with a draft of 2.80 meters (expansion phase 1). In phase 2, 'Upgrading Twente Canals,' the remaining part of the waterway is being made suitable for Class Va/M8 ships with a draft of 3.50 meters between the IJssel and Lock Eefde (Voorpand). Between Delden and Enschede (main branch) and the branch to Almelo, the waterway is being made suitable for Class Va ships with a draft of 2.80 meters.

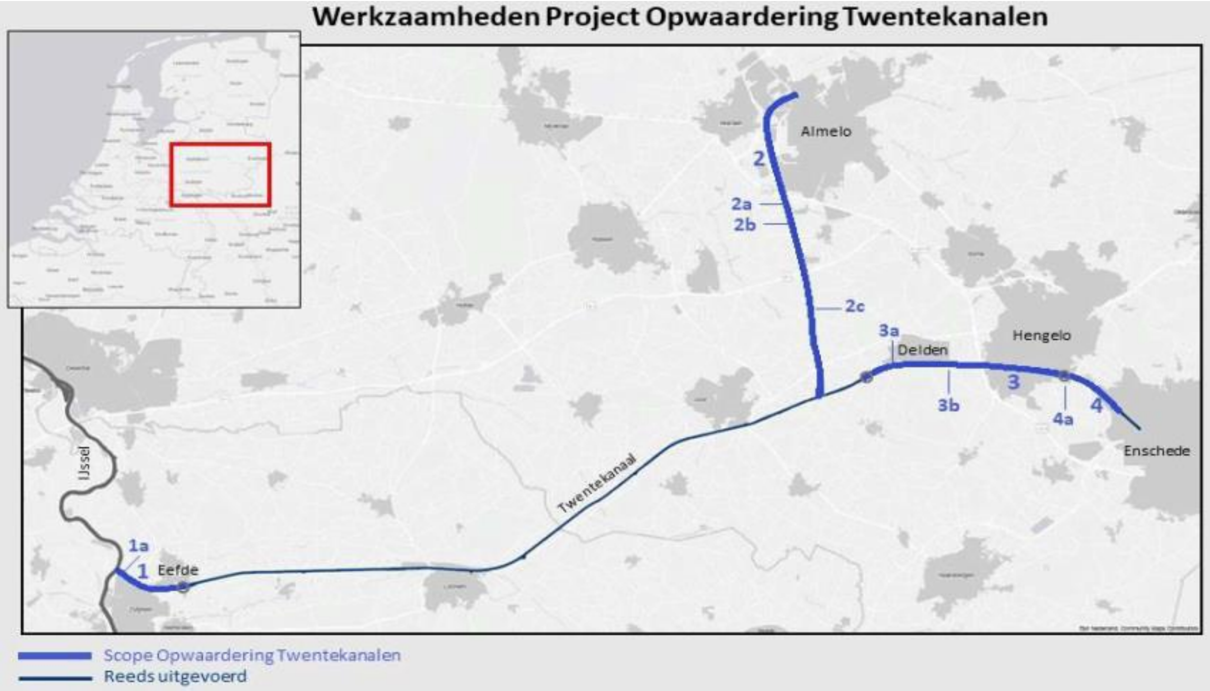


Figure 1-1 main outline of the route project Opwaardering Twentekanalen

In the Side Branch to Almelo, north of the A35, at approximately kilometre points 10.610 to 10.790, a test section with composite sheet piles has been set up over a length of approximately 180 meters.

Figure 1-2 Lest location

Rijkswaterstaat intends to use these locations to gain experience in designing, constructing, and maintaining composite sheet piles for their waterways.

1.2 Goal of this document

To successfully apply these composite sheet piles, a testing program has been established with the objective of verifying the material properties as specified by the supplier and gaining a better understanding of the material's performance.

This paper will present the results obtained from the **full-scale tests outside** conducted on the composite sheet piles.

The primary objective of this test is to evaluate the response of the sheet piles in real live conditions. Tree test setup have been prepared with different anchor connections. The angle of the anchor is the same for all three cases.

In order to implement composite sheet piles on a large scale in the Netherlands, it is crucial to adapt these sheet piles to the specific soil conditions prevalent in the country. In Dutch construction practices, steel sheet piles with grout anchors are commonly utilized. The grout anchor is inserted into the ground at an angle and tensioned against an anchor plate mounted on the sheet pile or the wale. Composite sheet piles must demonstrate the capability to withstand comparable anchor forces as possible on steel sheet piles.

Typically composite sheet piles are equipped with low-capacity anchors due to limited force transmission with the composite material. The commonly used self-drilling anchors in the Netherlands are efficient in that they can withstand high forces and can be implemented with minimal environmental impact. The combination of high anchor forces and composite sheet piles has never been attempted before. This implies that the composite sheet pile will be subjected to a loading condition that has not been tested previously, and the actual capacity of the composite sheet pile under such loading is uncertain. Laboratory tests will be conducted to gain insight into local failure mechanisms, especially buckling.

2 Test and Material

This paper will present the results obtained from full-scale tests. The tests were conducted on 7.1-meter-long sheet piles, with grout anchors installed every 2.743 meters at an anchor angle of 45 degrees. This angle was selected to replicate a common anchoring scenario prevalent in the Netherlands. To simulate realistic conditions, hydraulic jacks were used to apply anchor forces during the test, providing a comprehensive representation of field scenarios. Three anchor connections were tested for the experiment, with three anchors loaded for each test section. Only the attachment of the anchor and the waling varies depending on the situation.

These sheet piles are constructed from pultruded glass fibre polyester composite and were manufactured by CreativePultrusions with part number 55860.179. The manufacturer has designated these piles as 'Superloc Sheet Piles – Series 1580-P (SS860).

SuperLoc® Sheet Piles - Series 1580 (SS860)

Part drawings and physical property sheets can be viewed at **CreativeCompositesGroup.com**

Physical & Mechanical Properties

Series 1580 (SS860) 18" (457.2mm) W x 8" (203.2mm) H Physical Properties	Imperial Value	Units	Metric Value	Units
Section Modulus	13.08	in^3/ft	703.22	cm^3/m
Moment of Inertia	54.01	in^4/ft	7375.52	cm^4/m
Typical Thickness	0.265	in	6.731	mm
Depth of Sheet	8	in	203.2	mm
Width of Sheet	18	in	457.2	mm
Weight (single pile)	6	lb/ft of sheet	8.93	kg/m of sheet
Angle of the web	30	°	30	°
Cross Sectional Area of Sheet	7.43	in^2	47.94	cm^2
Standard Color	Graphite Gray			

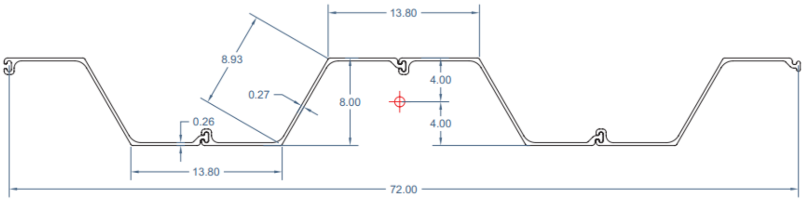
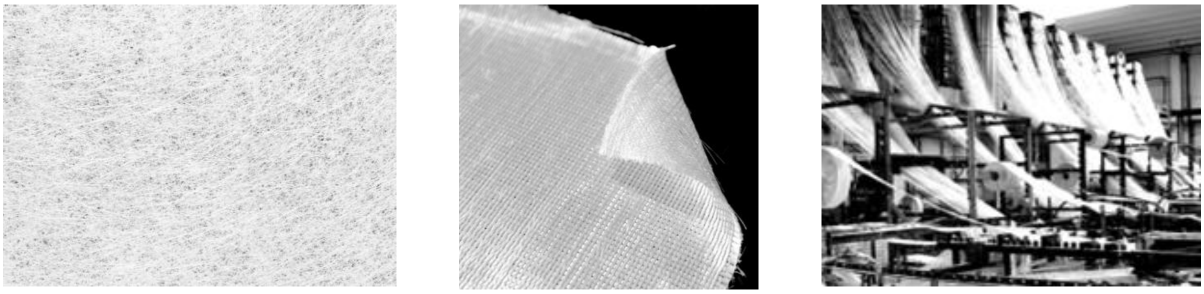


Figure 2-1 Superloc Series 1580

The glass fibre volume concentration is approximately 50%, comprising:

- A continuous filament mat volume of 2.22%,
- A 0/90 volume of 12.22% (6.11% in each direction),
- And 35.33% in the 0-direction (glass fibres on bobbins).

Figure 2-2 provides a visual representation of these directions. The remaining 50% of the volume is composed of polyester resin.



Continuous Filament 0/90 Fabric 0 Direction

Figure 2-2 Visual representation glass fibres used

3 Location

The test is conducted near "Gronddepot" De Bree along the Kanaalweg on the south side of the Twentekanaal, near Goor in the Netherlands. The exact test site location is shown in the figures below.

Figure 3-1 Project location test set-up

Figure 3-2 Terrain test set-up

4 Design

For the test, a readily available location was chosen where the test could be conducted safely, and the soil conditions were common for standard situations in the Netherlands and comparable to the conditions for "het Twentekanaal". For practical reasons, the same sheet pile length as that used in the Twentekanaal was employed. The retaining height is set at 2.5 meters. The maximum excavation depth has been determined based on the unanchored condition. The sheet pile is designed to be strong enough to stay in place in an unanchored situation for the safety of the people performing the test and standing close to the sheet pile during the test.

The anchor plate, the waling, the grout anchors, and the bolted connections are designed with a safety margin in such a way that they will never fail before the composite sheet pile.

Self driven anchors are used with a diameter Ø 42,4 x 11,0 and screw head of 180 mm. The grout body has a length of 5 meters and a thickness of 220 mm. To ensure an adequate safety margin regarding the holding force of the grout body, the grout body is oversized, designed with a holding force of 400 kN per anchor. Sufficient soil investigations is conducted in advance to gather information about the subsurface conditions. The complete soil investigation is included in Appendix A and the soil composition is specified in table 4-2 and Figures 4-2 and 4-3.

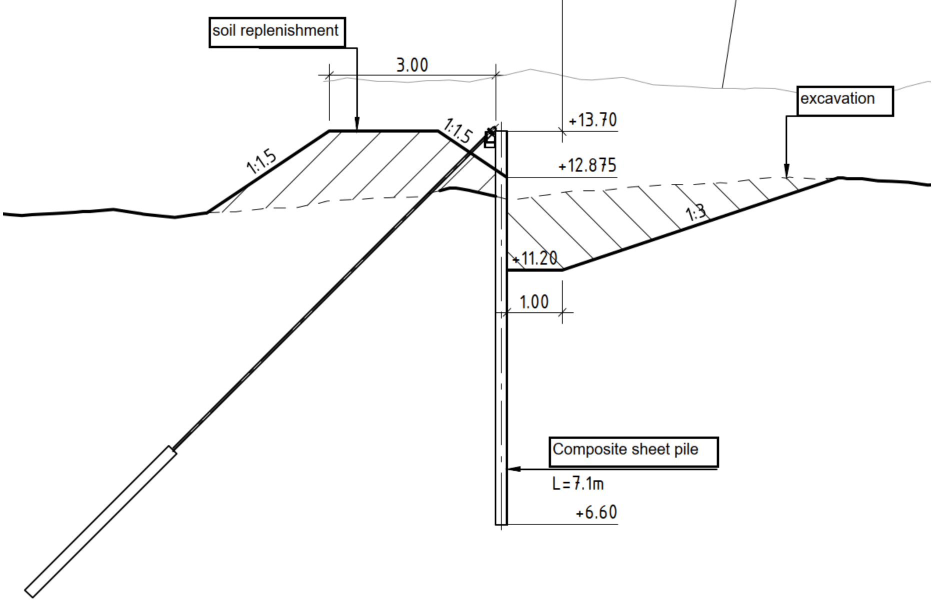


Figure 4-1 Cross-section set-up

Description	Properties
Sheet pile type	1580P
Flexural Rigidity	1520 kNm²/m
Elastic Rigidity EA1	266700 kN/m
Elastic Rigidity EA2	13340 kN/m
Top sheet pile	NAP +12,7 m
Tip sheet pile	NAP +5,60 m
Length sheet pile	7.1 m
Anchor spacing	2.743
Anchor angle	45°
Anchor Engagement Level	NAP +12.2 m

Table 4-1: Design properties

Soil type	Top layer [m NAP]	$\gamma_{nat}/\gamma_{sat}$ [kN/m³]	c' [kPa]	ϕ' [°]
Sandy soil, moderated-packed	12.7	18/20	0.2	39.9
Sandy soil, loose-packed	12.0	17/19	0.0	36.6
Sandy, clayey soil	9.5			
Sandy soil, moderately compacted	8.0-8.5	18/20	0.2	39.9

Table 4-2: Test results test 1 location 3

Water level: NAP +11.7 m (1.0 m below ground level).

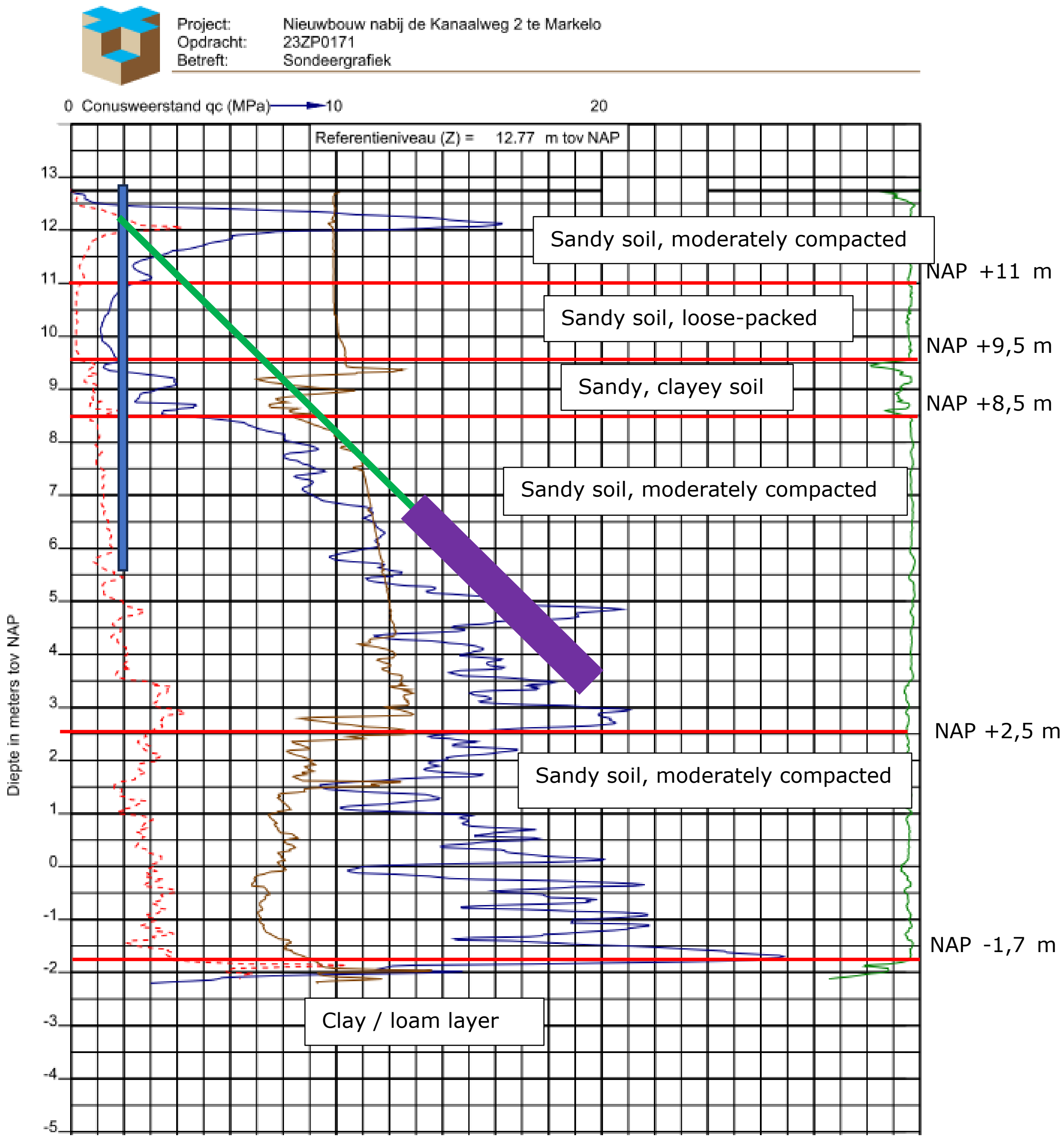


Figure 4-2 Soil composition (1)

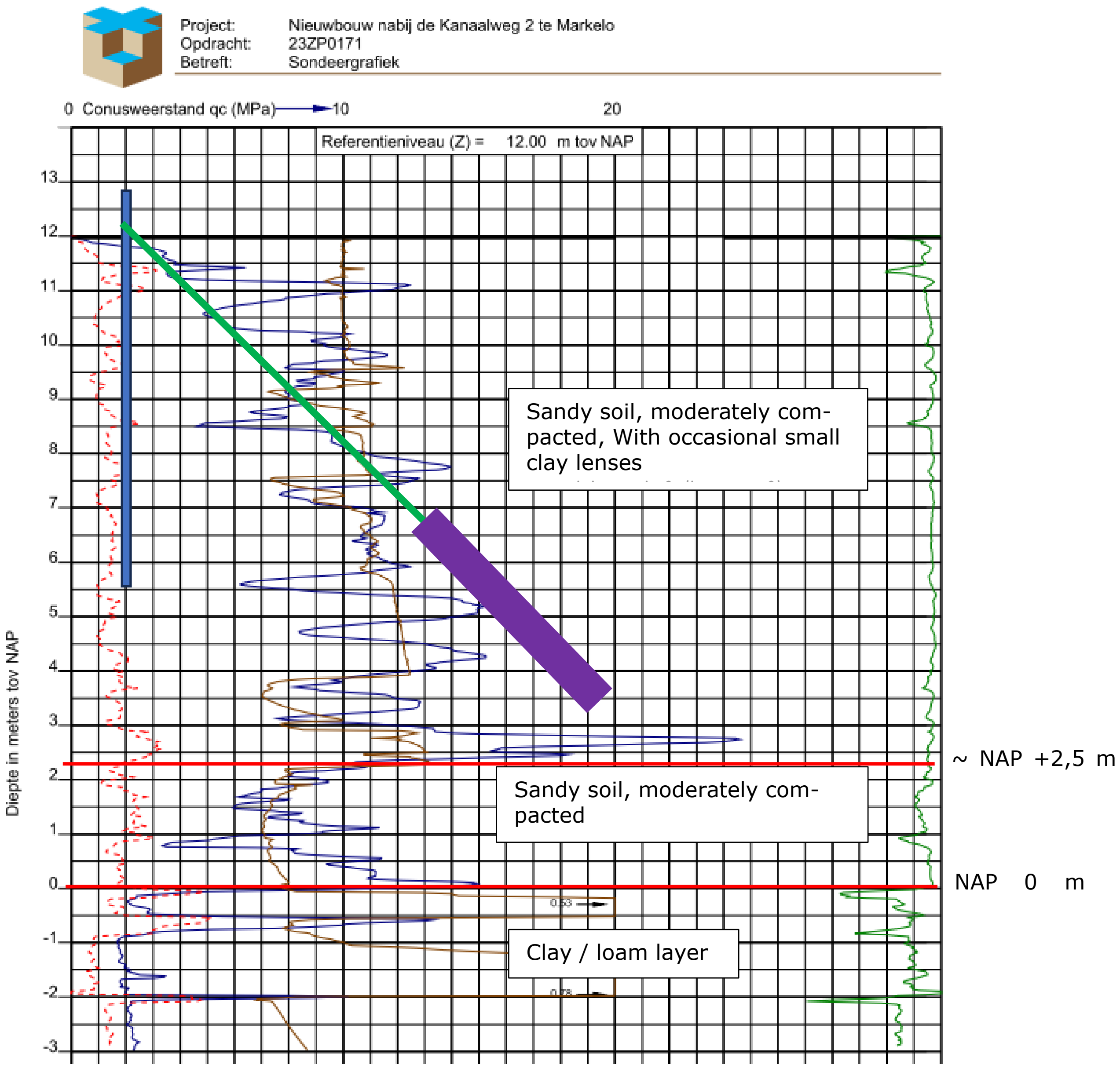


Figure 4-3 Soil composition (2)

During the test, the sheet piles are pressed towards the ground using hydraulic jacks. In reality, the load behind the sheet pile will increase, causing it to move forward. The test-setup and a real situation will result in a different behaviour of the soil. The test setup activates a passive soil wedge. I normal situations, an active soil wedge is formed. The two different situations have been compared, and it appears that in all cases, the test setup yields lower overall forces in the sheet pile. This underestimates reality, but in this case, it is not a problem since the overall capacity of the composite sheet pile is much greater than the local capacity. Therefore, the composite sheet pile will always fail around the anchor force introduction.

5 Installation

The installation of the composite sheet piles is carried out using a hydraulic Volvo 300 crane, equipped with a high-frequency vibratory hammer. To prevent potential damage to the composite sheet piles during the vibrating installation process, a steel auxiliary steel sheet pile is used. This auxiliary steel sheet pile is prefabricated to comply with the form of the composite sheet pile.

The composite sheet pile is lifted into the auxiliary steel sheet pile by the 3.5-ton auxiliary crane. Subsequently, the composite sheet pile is attached to the auxiliary steel sheet pile using clips. This prevents soil from getting between the sheets, avoiding any separation. After vibrating the sheet pile to the desired depth, the auxiliary steel sheet pile is extracted. The plastic sheet pile remains in place, and the clips also remain embedded in the soil.

Figure 5-1 Auxiliary sheet pile with clips

To prevent interference between the tree test set-ups the composite sheet pile profiles between the three waling and anchor plate options are not interlocked.

After the installation of the new composite sheet piles is completed, a steel waling is installed, which is mounted to the sheet pile through bolt connections. For this purpose, three different walings with anchor plates have been prefabricated.

A different type of waling is applied for each option. Prefabrication is done in waling sections of 9.1 m (equivalent to 10 composite sheet pile planks). The walings are not connected on-site. The holes for attachment to the composite sheet piles are made on-site.

After the installation of the composite sheet piles is completed, the anchors are drilled and installed using an anchor drilling machine. Once the anchor reaches the desired depth, a grout mixture is pressurized into place. This process creates a grout column at depth, which, upon curing, is intended to provide the actual anchoring of the sheet pile.

For steel sheet piles, the threaded part of the grout anchor is guided through a hole in the sheet pile. For composite sheet piles, it is necessary to keep this hole as small as possible, preventing the threaded part from being guided through the hole.

The test was conducted by tensioning the anchors, pressing the sheet pile against the ground using hydraulic jacks.

At one location, the sheet pile did not interlock during installation. This is likely to have a limited impact on the test results, as the significantly stiffer steel wale will distribute the load in the transverse direction.

Figure 5-2 Sheet pile lost interlocking

6 Preparation and measuring equipment used

The tests were conducted on Monday, June 12, and Tuesday, June 13. The experiment involved monitoring three components:

1. Anchor forces;
2. Deformations of the sheet pile and waling;
3. Visual inspection using cameras.

Three hydraulic jacks are used per test location. The jack force is incrementally increased at fixed intervals of 5 kN, see measurements in appendix E. At each time step, the displacement of the sheet pile is measured, enabling the correlation between displacement and load to be established, see appendix F. In addition, the entire test was monitored with cameras to capture the failure behaviour. The measurement of the displacement are logged with a total station and the measurements of the hydraulic jacks is written down. There is some time difference between the logged measurements and the hand written measurements. In post-processing the measurements are aligned to give an accurate overview off what had happened during the test.

Before the start of the tests a baseline measurement has been done, see appendix B.

The sheet piles are pulled towards the ground by the hydraulic jacks. The measured displacements have a positive value when the movement is towards the ground and a negative value when the sheet piles would displace in forward direction.

Figure 6-1 Total station+ 3 hydraulic jacks in the back

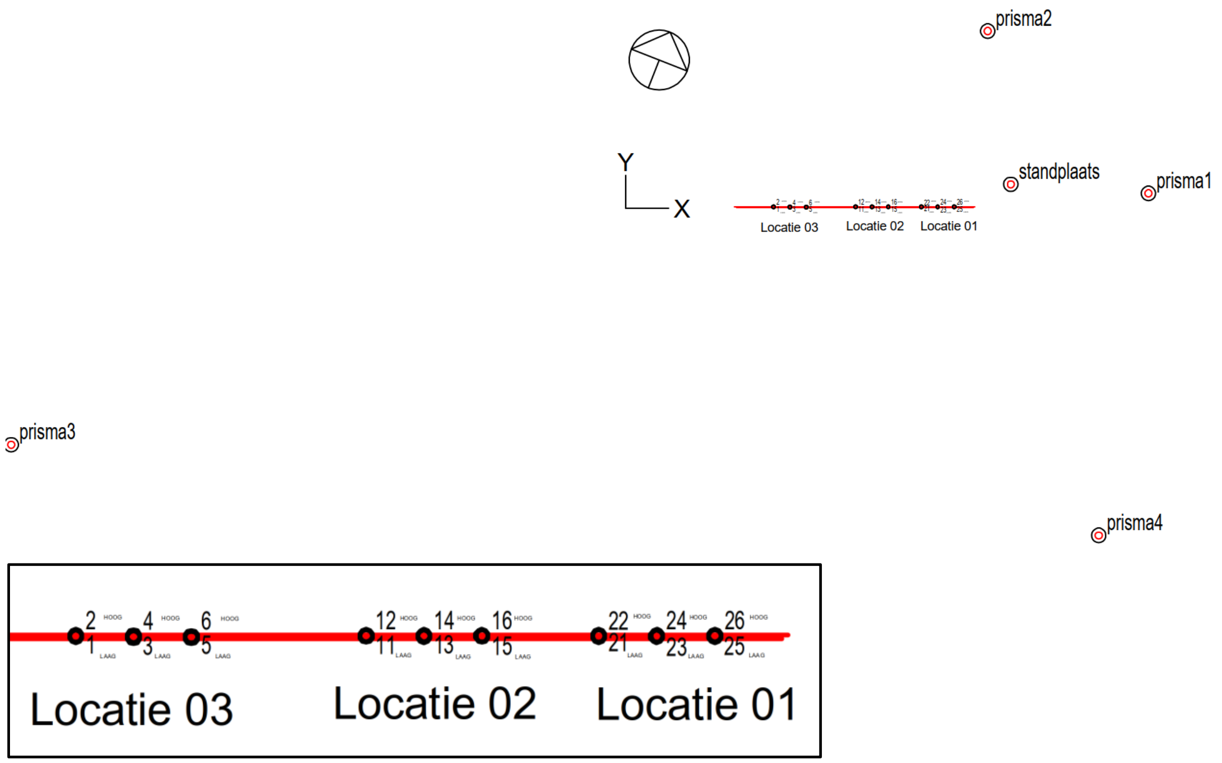


Figure 6-2 Measurement points

Figure 6-3 Yellow dots indicate high and low measurement points

Figure 6-4 3 Set-up with the hydraulic jacks

6.1 Test 1 location 3

In Test Setup 1, the wale is situated at the rear of the sheet pile using a bolted connection. The bolts traverse through the sheet pile and are fastened at the front to a steel plate that spreads the force within the sheet pile. The anchor plate is positioned on top of the wale and welded using sketch plates. The anchor force generates a bending moment in the wale, resulting in a tensile force on the upper row of bolts and a compressive force on the lower part of the wale. This chosen option avoids the necessity of creating a hole in the sheet pile for the passage of the anchor. This choice was made because the maximum hole diameter recommended by the supplier is 50 mm. When installing a traditional grout anchor at an angle, an oval hole with a height of 150 - 200 mm is often required and during installation, the anchor rod can damage the sheet pile.

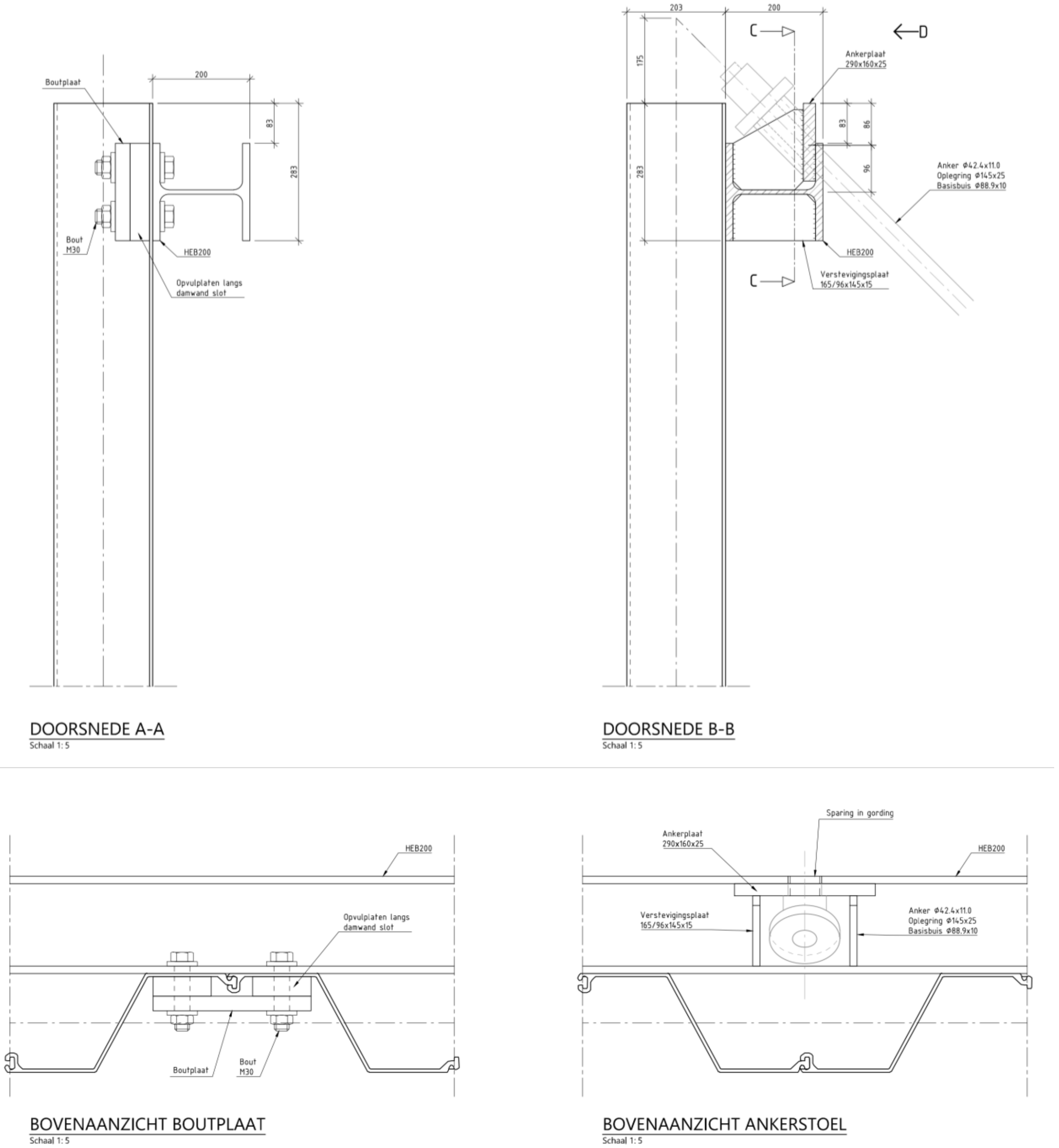


Figure 6-5 Sheet pile connection test 1

Figure 6-6 Sheet pile connection test 1

Figure 6-7 Sheet pile connection test 1

6.2 Test 2 location 2

In Test Setup 2, the anchor waling is also placed at the back of the sheet pile, but the anchor plate is located at the front. The anchor waling is connected to the sheet piles at the unanchored part with a bolted connection. At the location of the anchor, an anchor plate with a shear plate is used to transfer the vertical forces. For the passage of the anchor rod, an oval hole with a diameter of 65 mm and a height of 100 mm is required. This hole is larger than the maximum diameter of 50 mm recommended by the supplier. The created hole is only large enough for the anchor rod but not for the anchor screw. Typically, the hole is adjusted to the diameter of the screw, but that would lead to too much weakening.

This option was chosen to evenly distribute the vertical force on a pultruded composite sheet pile by using the shear plate. The horizontal anchor force is introduced through the anchor plate.

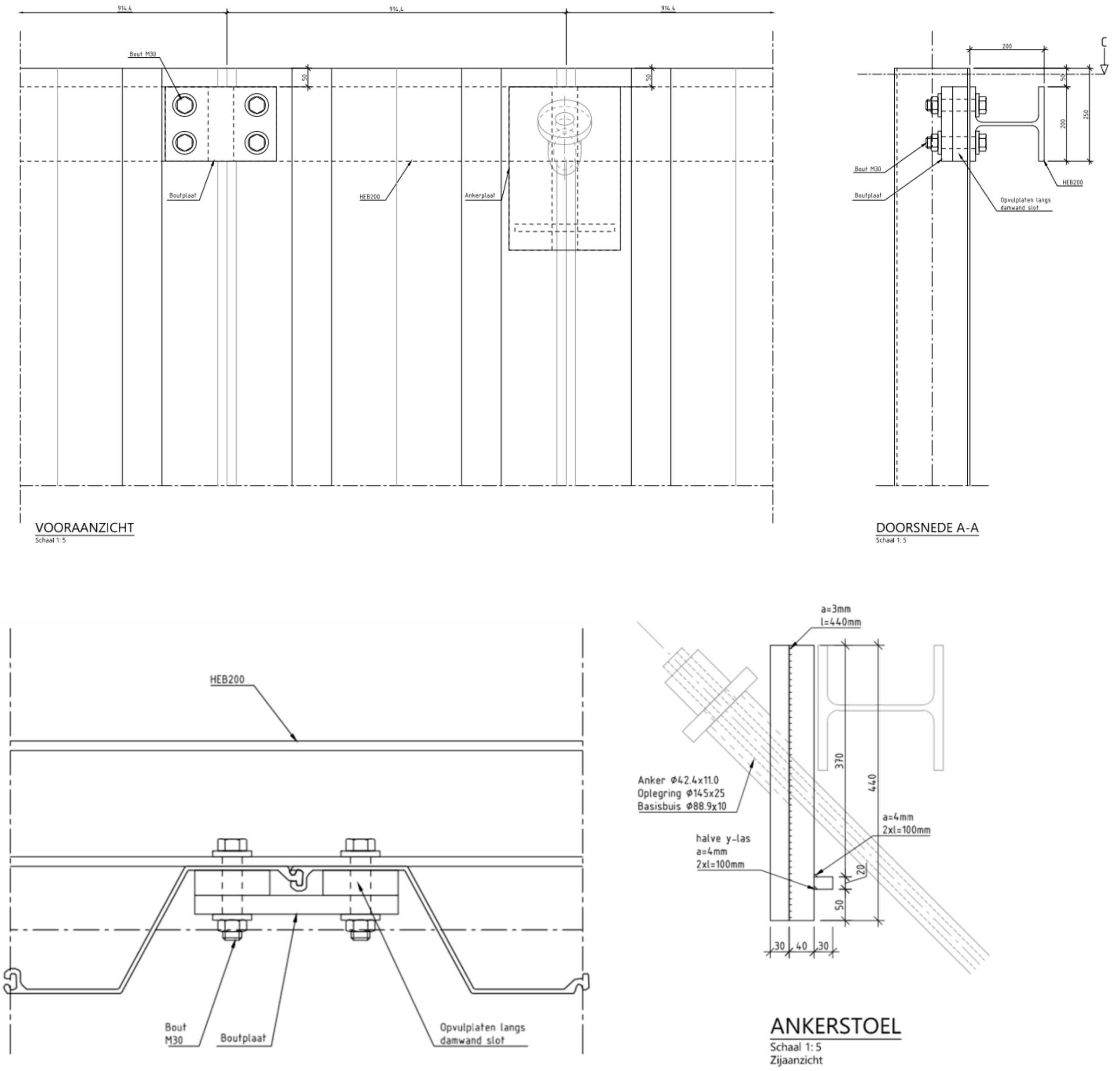


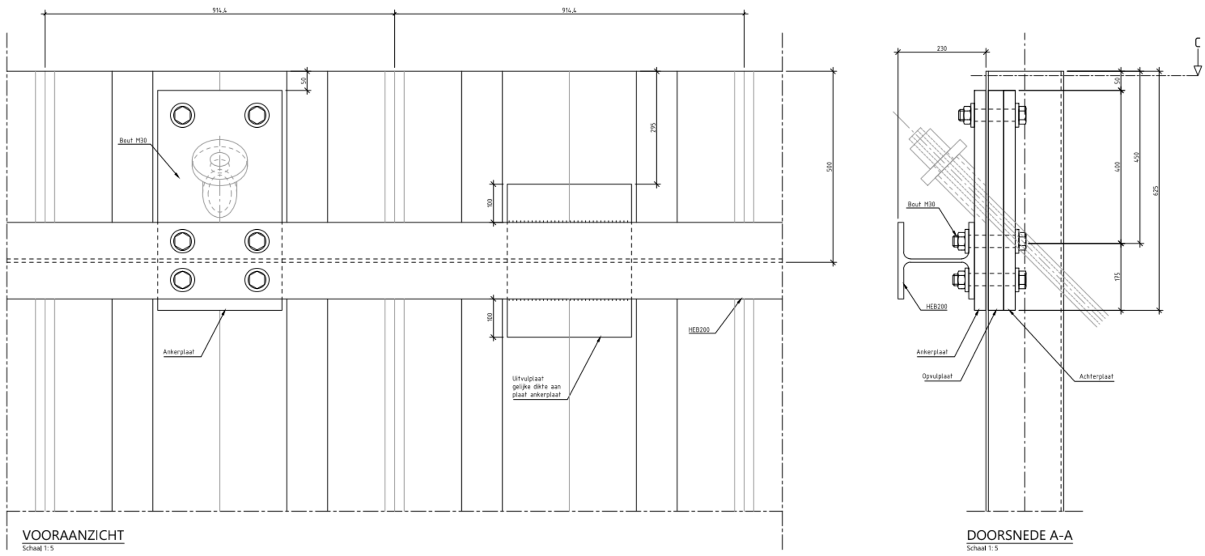
Figure 6-8 Sheet pile connection test 2

Figure 6-9 Sheet pile connection test 2

6.3 Test 3 location 1

In Test Setup 3, the anchor waling is positioned at the front of the sheet pile (= typically the water side). The anchor waling is connected to the anchor plate and the anchor via a bolted connection. At the locations where there is no anchor, a steel (filler) plate is used, which directly transfers the soil pressure from the sheet pile to the anchor waling. The bolts transfer the vertical loads and the anchor plate the horizontal loads. For the passage of the anchor rod, an oval hole with a diameter of 65 mm and a height of 100 mm is required. This hole is larger than the maximum diameter of 50 mm recommended by the supplier. The created hole is only large enough for the anchor rod but not for the anchor screw. Typically, the hole is adjusted to the diameter of the screw, but that would lead to too much weakening.

This option was chosen to evenly distribute the vertical force on a pultruded composite sheet pile by using bolts in stead of a shear plate. The bolts plus the anchorplates on both sides of the sheetpile prevent local buckling. The horizontal anchor force is introduced through the anchor plate.



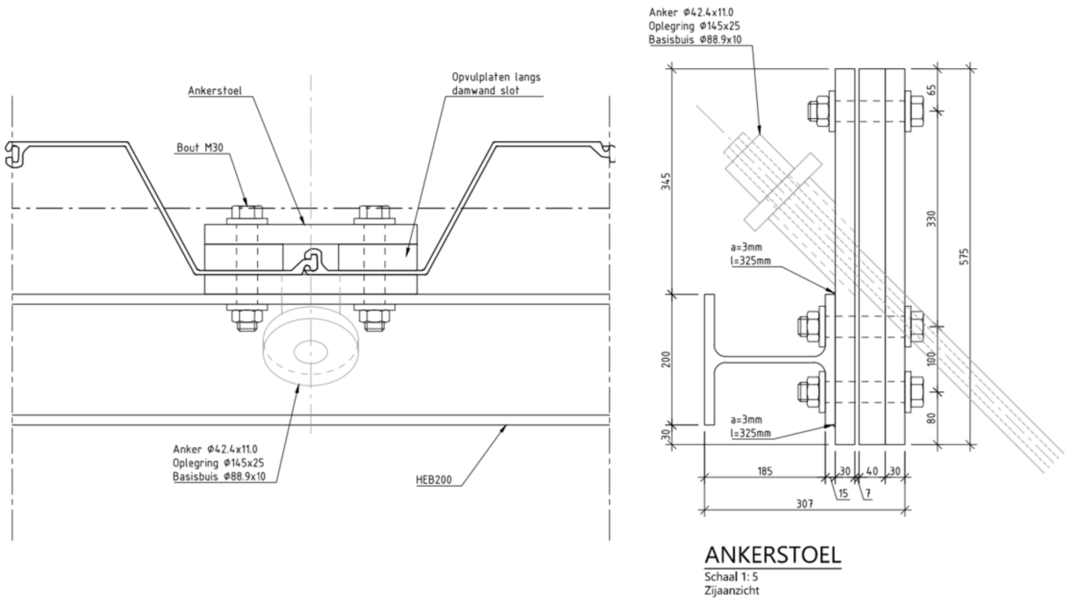


Figure 6-10 Sheet pile connection test 3

Figure 6-11 Sheet pile connection test 3

7 Results

7.1 Test 1 location 3

In the process of increasing the hydraulic pressure from 25kN to 30kN, a creaking sound from the sheet pile is observed, and initial damage (first failure) is noted at the connection plates located left and right of the anchors loaded by hydraulic jack LC3045 and LC3046. At 35kN, the sound of fibre breakage becomes very noticeable. The composite sheet pile loaded by hydraulic jack LC3045 is the first to fully fail under a maximum force of 45kN due to punching shear of the connection plates left and right of the anchor. Due to the bending moment transferred by the wale, the connection plates have a higher contact pressure at the top than at the bottom. Therefore, you can see the first punching shear at the location with the highest contact pressure, the top part. The capacity of this option can be increased by enlarging the contact surface of the connection plates or by making more connections with the composite sheet pile and the waler, allowing for a more even distribution of the load.

Hydraulic jack	Measure point	Max. load hydraulic jacks (kN)
LC3045	6	44.7
LC3047	4	45.2
LC3046	2	45.5

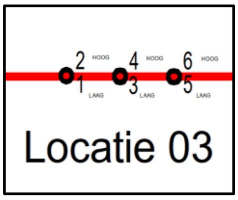


Table 7-1: Test results test 1 location 3

The figure below provides a visual representation of the measurement results. The individual points depict the increase in hydraulic pressure (on the left axis) plotted against the progression of time. The solid line with intermediate points illustrates the displacement (on the right axis) of the upper measurement points plotted against the progression of time. After releasing the force, the sheet pile does not fully return to its original position. The displacements of the lower points are negligible (0 - 1 mm).

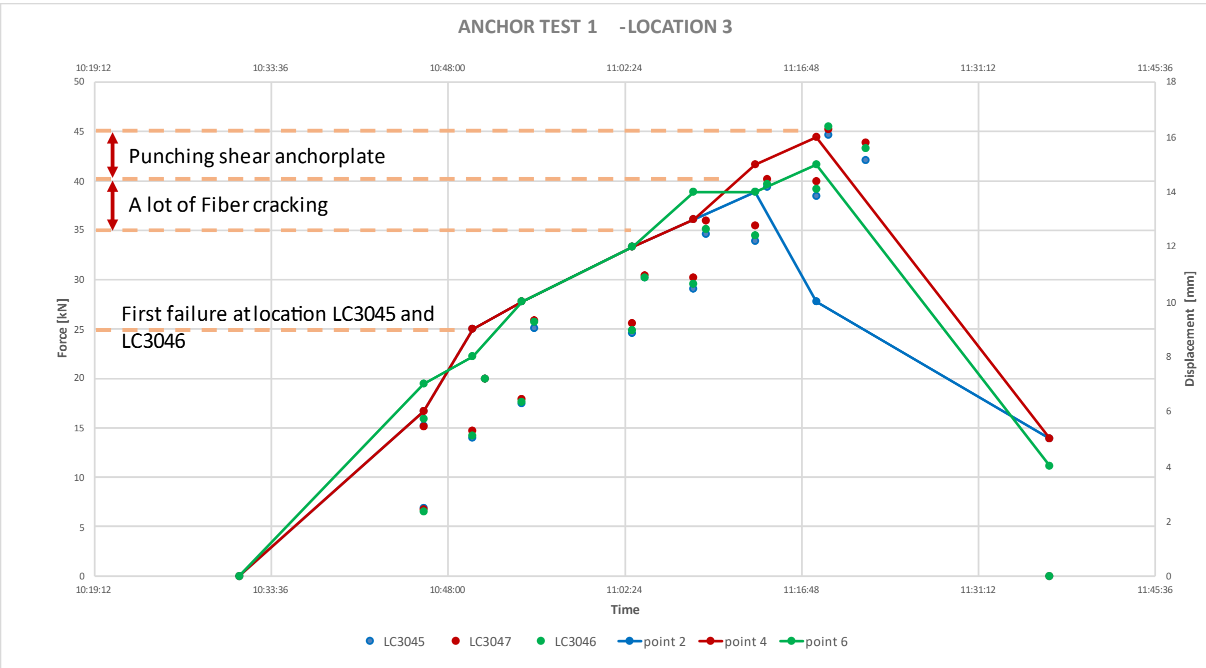


Figure 7-1 Results test 1 - location 3

7.2 Test 2 location 2

In the process of increasing the hydraulic pressure, fibre cracking is observed at a pressure of 55kN, but no damage is noted. The sound of fibre cracking continues from this point on until local failure is noted at 75kN underneath the noise plate. At around 85kN, the maximum achievable pressure is reached. Failure occurs due to buckling of the outer laminate layer followed by the buckling of the inner fibres.

The disadvantage of this option is that a hole in the sheet pile must be made for both the passage of the anchors and the nose plate. It should be noted that the nose plate works very effectively.

Hydraulic jack	Measure point	Max. load hydraulic jacks (kN)
LC3045	16	85.3
LC3047	14	86.4
LC3046	12	84.7

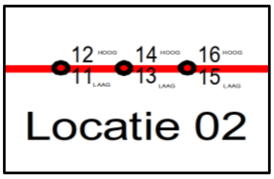


Table 7-2: Test results test 2 location 2

The figure below provides a visual representation of the measurement results. The individual points depict the increase in hydraulic pressure (on the left axis) plotted against the progression of time. The solid line with intermediate points illustrates the displacement (on the right axis) of the upper measurement points plotted against the progression of time. After releasing the force, the sheet pile almost returns to its original position. The displacements of the lower points are negligible (0 - 1 mm).

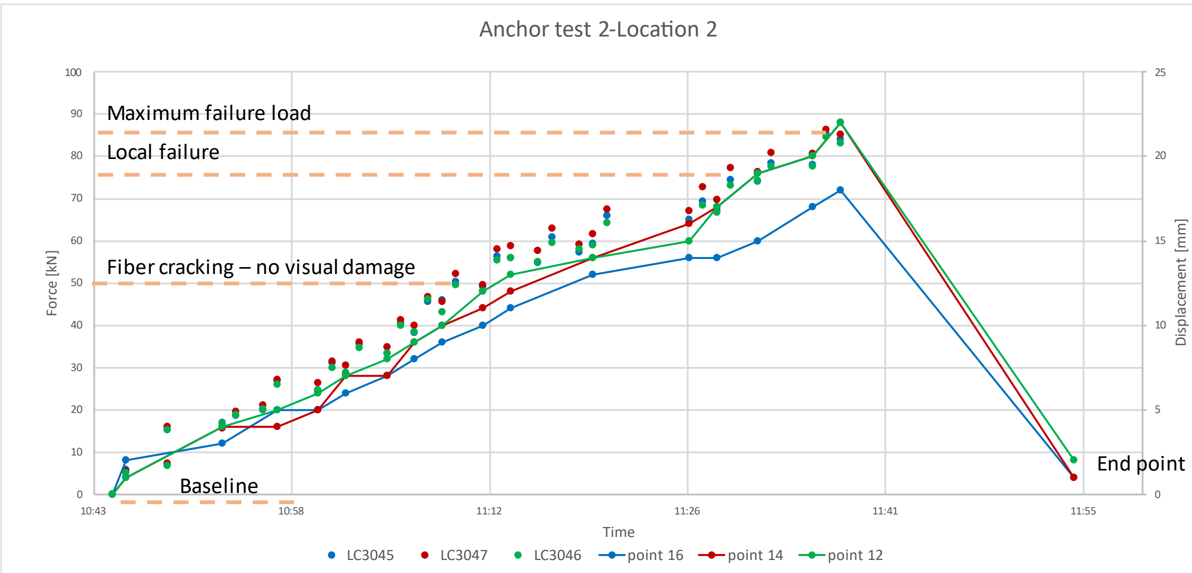


Figure 7-2 Results test 2 - location 2

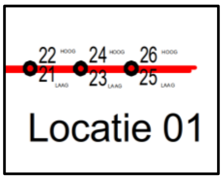
7.3 Test 3 location 1

In this option, the least fibre breakage is audible and only occurs at a very high hydraulic pressure in comparison to the first two tests. This is because local failure is mostly prevented by the front and back steelplate. Furthermore the steelplate introduce the loads more evenly.

At a hydraulic pressure of 90kN local failure is noted, but the hydraulic pressure can still be increased to above 125kN until the maximum absorbable force is reached.

Hydraulic jack	Measure point	Max. load hydraulic jacks (kN)
LC3045	26	126.6
LC3046	24	130.9
LC3047	22	129.8

Table 7-3: Test results test 3 location 1



The figure below provides a visual representation of the measurement results. The individual points depict the increase in hydraulic pressure (on the left axis) plotted against the progression of time. The solid line with intermediate points illustrates the displacement (on the right axis) of the upper measurement points plotted against the progression of time. After releasing the force, the sheet pile almost returns to its original position. The displacements of the lower points are negligible (0 - 1 mm).

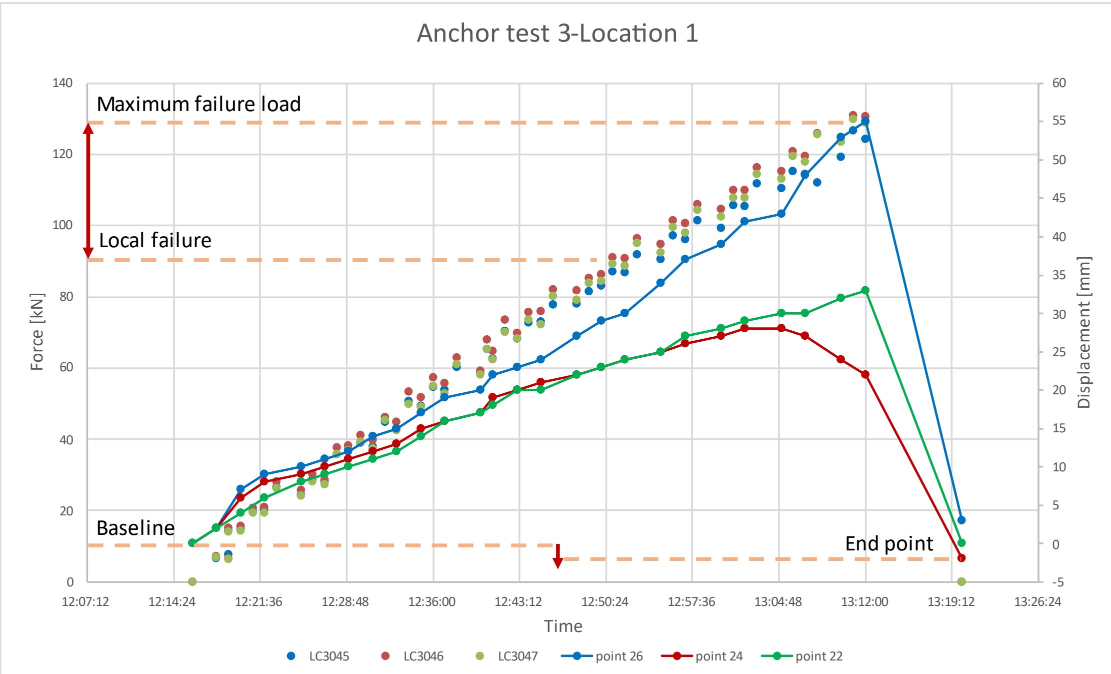


Figure 7-3 Results test 3 - location 1

If a design deviates from the supplier's standard and is built with grout anchors, it is advisable to create a design according to option 3. This option provides the highest failure capacity and the least local damage and failure.

8 Determining the characteristic values

To determine the characteristic values, the CUR96 guidance is used. The characteristic value of a property is determined by the following formula:

$$R_k = m_x * (1-k_n*V_x)$$

Where:

R_k = Characteristic value

n = number of tests

V_x = Which is the coefficient of variation $V_x = S_x/m_x$

S_x = Standard deviation

m_x = average value

k_n = Static factor which can be calculated with $k_n = K* (1+1/n)^{1/2}$, or k_n can be retrieved from Table 5-1.

K = 1.645, for the 5% underestimate value in a normal distribution

n	1	2	3	4	5	6	8	10	20	30	∞
V_x known	2,31	2,01	1,89	1,83	1,80	1,77	1,74	1,72	1,68	1,67	1,64
V_x unknown	-	-	3,37	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 8-1: k_n values

Determining the characteristic value, in this case, does not add much value due to an insufficient number of tests conducted to achieve a statistically correct distribution. If there is only one test result available, it is not possible to calculate the standard deviation. The standard deviation is a measure of the spread of data, but to calculate it, multiple observations are required. With only a single measurement, there is no basis to assess the variability of the data, and therefore, a standard deviation cannot be determined. The concept of the standard deviation implies a set of data to measure variability.

9 Bearing responds

9.1 Maximum strength

9.1.1 Test 1 location 3

Ultimate load test 1		
Measure point	**Strain (kN)**	**Deviation (kN)**
2	45.5	45.5
4	45.2	45.2
6	44.7	44.7
Average (kN)	45.1	
Standard deviation (kN)	0.3	
Coefficient of variation (%)	0.73	
K	1.645	
kn	1.899	
n	3	
Rk	44.5	kN

Table 9-1: Ultimate load test 1

9.1.2 Test 2 location 2

Ultimate load test 2		
Measure point	**Strain (kN)**	**Deviation (kN)**
12	84.7	84.7
14	86.4	86.4
16	85.3	85.3
Average (kN)	85.5	
Standard deviation (kN)	0.7	
Coefficient of variation (%)	0.82	
K	1.645	
kn	1.899	
n	3	
Rk	84.1	kN

Table 9-2: Ultimate load test 2

9.1.3 Test 3 location 1

Ultimate load test 3		
Measure point	**Strain (kN)**	**Deviation (kN)**
22	129.8	129.8
24	130.9	130.9
26	126.6	126.6
Average (kN)	129.1	
Standard deviation (kN)	1.8	
Coefficient of variation (%)	1.41	
K	1.645	
kn	1.899	
n	3	
Rk	125.6	kN

Table 9-3: Ultimate load test 3

9.2 Failure mode

9.2.1 Test 1 location 3

In test 1, the connection plate is punched through the sheet pile. Due to the bending moment the pressure at the top is higher than at the bottom causing failure at the location with the highest pressure. When the steel plate is partly punched through, the sheet pile delaminates.

Figure 9-1 Punching shear connection plate and delamination

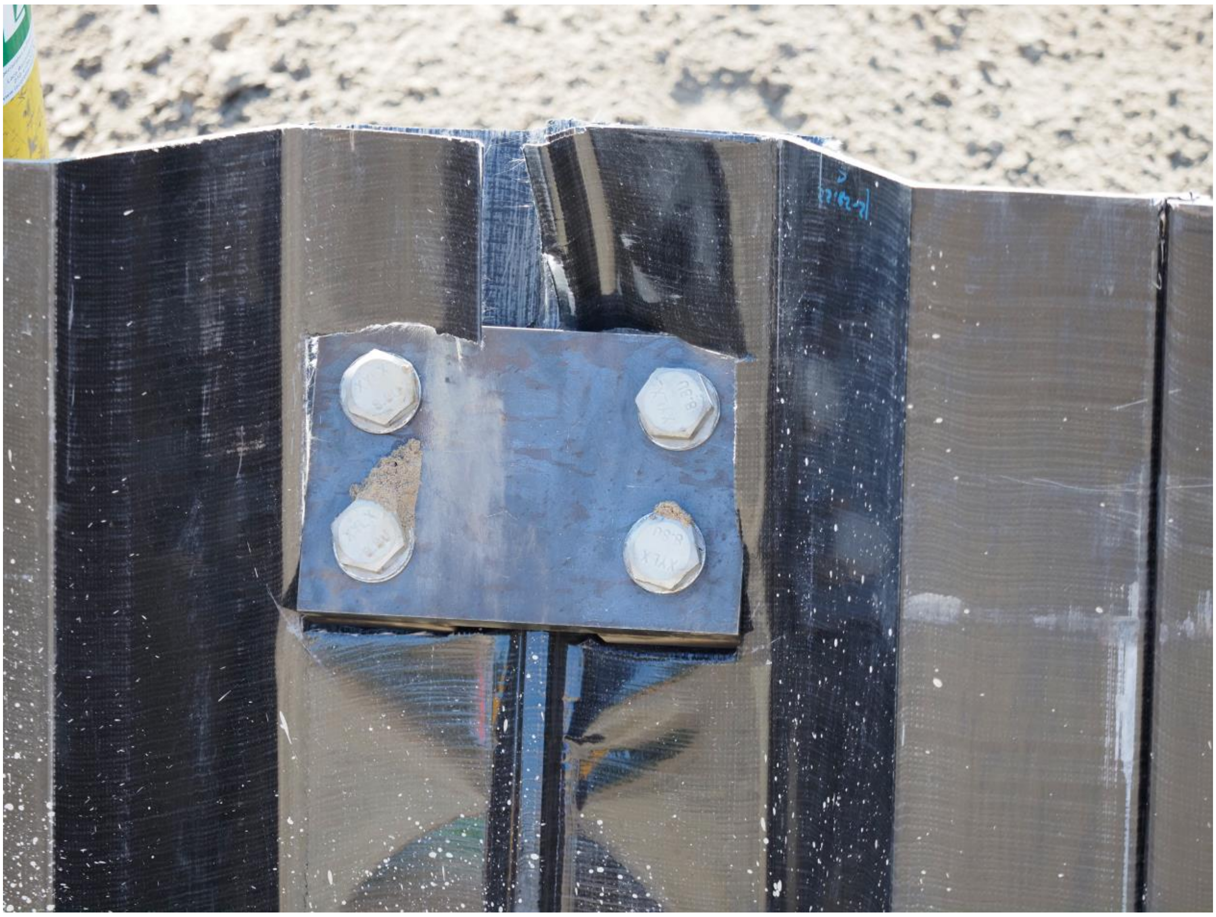


Figure 9-2 Punching shear connection plate and delamination

Figure 9-3 Punching shear connection plate and delamination


Figure 9-4 Punching shear connection plate and delamination

9.2.2 Test 2 location 2

The pressure of the shear plate causes local buckling and delamination of the outer 0/90 laminate layer.

Figure 9-5 Local buckling and delamination of the outer 0/90 laminate layer

Figure 9-6 Local buckling and delamination of the outer 0/90 laminate layer

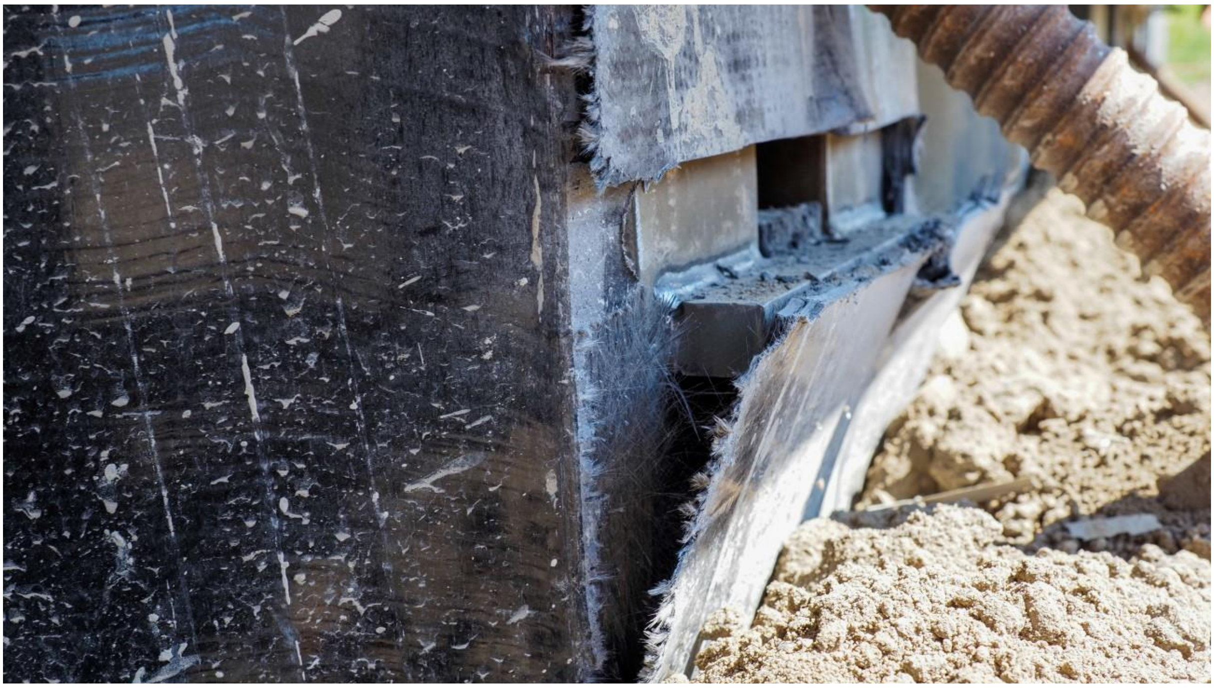


Figure 9-7 Local buckling and delamination of the outer 0/90 laminate layer

Figure 9-8 Local buckling and delamination of the outer 0/90 laminate layer

Figure 9-9 Local buckling and delamination of the outer 0/90 laminate layer

Figure 9-10 delamination and failure of the outer laminate layer

9.2.3 Test 3 location 1

Due to the robust dimensions of the steel plate, minimal practical preload is applied when tightening the bolts. As a result, the sheet pile fails not only locally due to bearing failure at the bolt but also because the outer 0/90 layer is peeled off and locally buckles.

Figure 9-11 Local buckling and delamination of the outer 0/90 laminate layer

Figure 9-12 Local buckling and delamination of the outer 0/90 laminate layer

Figure 9-13 Local buckling and delamination of the outer 0/90 laminate layer

10 Summary

Summarizing the results from the full scale tests outside, the following outcomes are obtained and presented in Table 10-1.

Test	Max. Failure load (kN)	Failure type
1 location 3	44.5	punching shear and delamination
2 location 2	84.1	local buckling and delamination
3 location 1	125.6	local buckling, bearing capacity and delamination

table 10-1 Failure loads according to full scale outdoor tests

11 Appendix

11.1 Appendix A – Geotechnical report

(23ZP0171-RG-01 Nieuwbouw nabij de Kanaalweg 2 te Markelo,14-2-2023)

Nieuwbouw nabij de Kanaalweg 2 te Markelo

INPIJN BLOKPOEL INGENIEURS

MEERWAARDE DOOR GRONDIGE KENNIS

Nieuwbouw nabij de Kanaalweg 2 te Markelo

Opdrachtnummer: 23ZP0171

Rapport betreffende
Resultaten geotechnisch onderzoek

Documentnummer
23ZP0171-RG-01

Versie
1.0

Datum rapport
14 februari 2023

Opdrachtgever
Combinatie Van Oord - Hakkers - Beens vof
Postbus 8574
3009 AN Rotterdam

Opgesteld door:

Vrijgegeven door:

INHOUDSOPGAVE

BIJLAGEN:

A Situatietekening en foto's
B Waterpasstaat
C Sondeergrafieken
D Verklaring codering

VERSIE

1.0 Rapportage

VERZENDLIJST:

- Per mail aan Opwaardering Twentekanalen te Rotterdam t.a.v. Dhr.
  (@hakkers.com)

1. INLEIDING

Ten behoeve van een nieuwbouw nabij de Kanaalweg 2 te Markelo is door ons bureau op verzoek van Combinatie Van Oord - Hakkers - Beens vof uit Rotterdam een geotechnisch onderzoek verricht. Voorliggend rapport bevat een beschrijving en de resultaten van het onderzoek.

2. ONDERZOEK

2.1 Sonderingen met kleef- en waterspanningsmeting

Op de projectlocatie zijn 6 sonderingen gemaakt met een elektrische conus conform NEN-EN-ISO 22476-1. Bij de sonderingen zijn de conusweerstand, de plaatselijke wrijving en de waterspanning gemeten en geregistreerd. De relatie tussen conusweerstand en plaatselijke wrijving, het wrijvingsgetal, geeft beneden het grondwaterniveau een indicatie van de verschillende grondsoorten. De sondering is uitgevoerd door een sondeertruck.
Voor de grafieken van de sonderingen wordt verwezen naar bijlage C; de locatie van de sondeerpunten is aangegeven op de situatietekening SIT-01 bijlage A.
Voor een verklaring van de op de tekening gebruikte tekens wordt verwezen naar de “Verklaring Codering” die onder bijlage D aan dit rapport is toegevoegd.

2.2 Inmeting

Van ieder onderzoekspunt (meetpunt) is de positie en de hoogte van het maaiveld ingemeten. De meting is uitgevoerd met een GPS-systeem. Het horizontale coördinatensysteem is RD; de verticale referentie is NAP.
Voor de omschrijving van de meetresultaten wordt verwezen naar bijlage B.

2.3 Foto’s

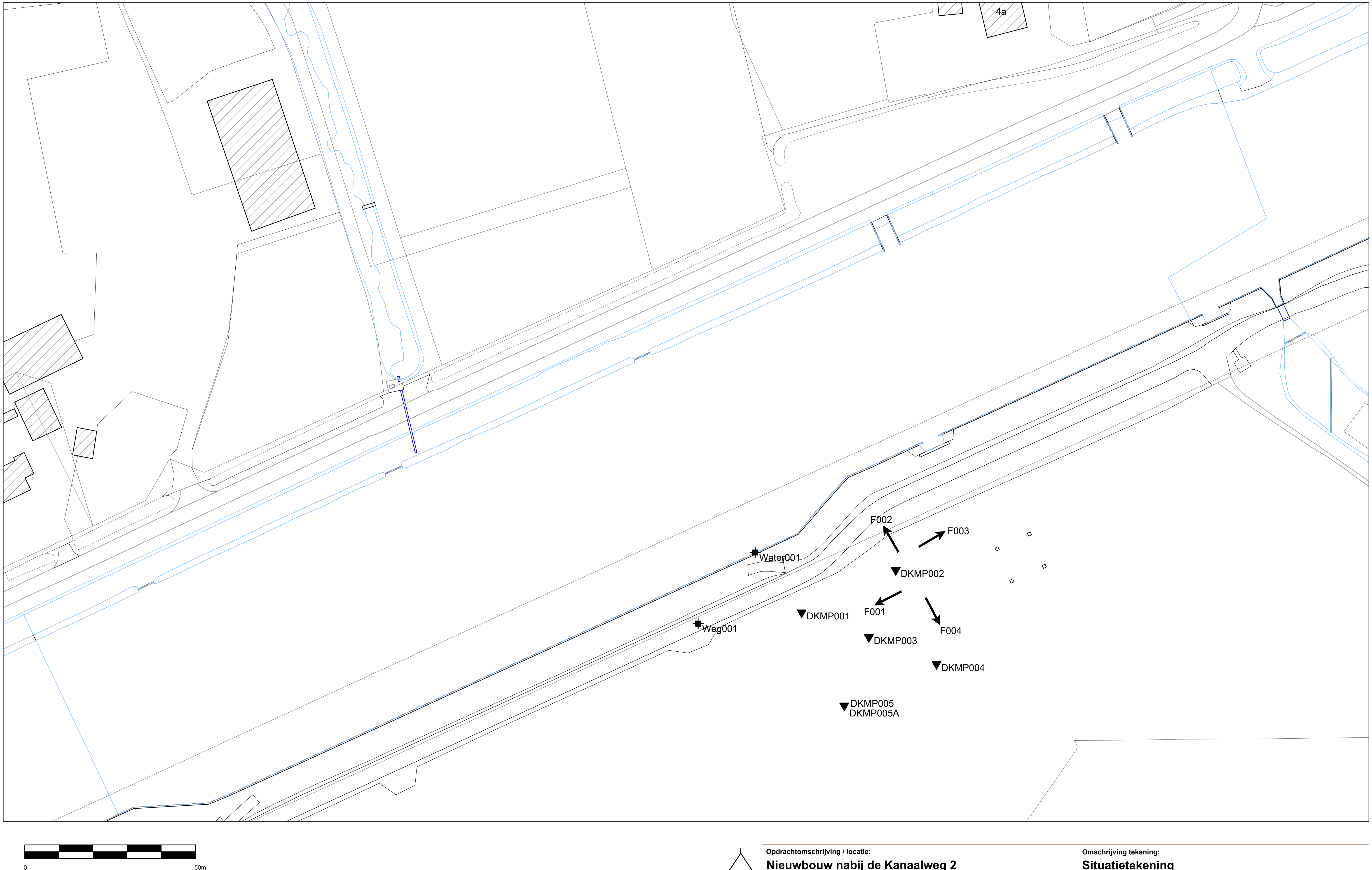
Tijdens de uitvoering van het veldwerk zijn enkele foto’s gemaakt. Voor de foto’s en een tekening waarop met pijlen is aangegeven vanuit welke positie en in welke richting de foto’s zijn gemaakt wordt verwezen naar bijlage A.

3. ADVISERING

Mocht u binnen het kader van dit project een geotechnisch, milieutechnisch en/of geohydrologisch advies wensen dan kunt u hiervoor contact opnemen met het hoofd van onze adviesafdeling ir. N.T. Debets.

Tot slot wijzen we erop dat Inpijn-Blokpoel Ingenieursbureau beschikt over een breed dienstenpakket op het gebied van de geo- en milieutechniek. Voor meer informatie hieromtrent verwijzen we naar onze website www.inpijn-blokpoel.com.

BIJLAGE A
Situatietekening en foto's



Opdrachtomschrijving / locatie:

Nieuwbouw nabij de Kanaalweg 2 te Markelo

Omschrijving tekening:

Situatietekening

INPIJN BLOKPOEL INGENIEURS

Bewerkt: **CSS/KGT**

Datum: **14 februari 2023**

Schaal: **1:1000**

Formaat: **A3**

Opdrachtnummer: **23ZP0171**

Bijlage: **SIT-01**

Deze situatietekening dient om inzicht te geven in de locatie van de meet- en onderzoekspunten. De tekening dient niet voor andere doeleinden te worden gebruikt.

n:\opdrachten\zuid\2023\01\23zp0171\06-veldwerk\04-tekeningen\23zp0171-sit-css.dwg


F001

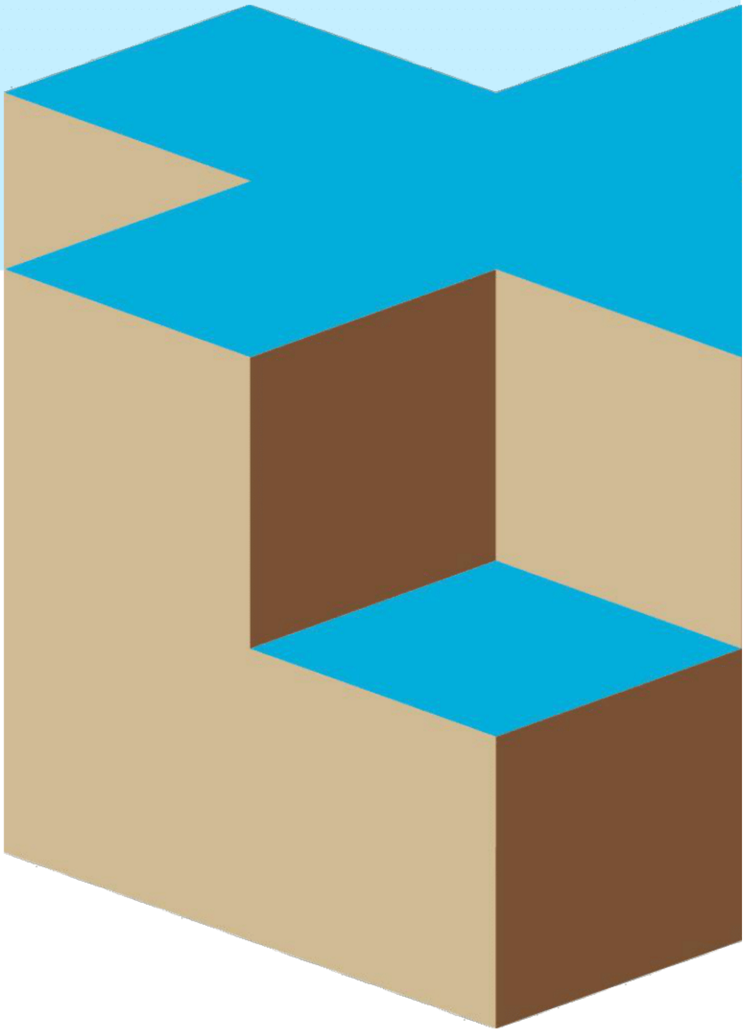

F002


F003


F004

Genomen op: 9 februari 2023

BIJLAGE B
Waterpasstaat



OVERZICHT MEETPUNTEN

Horizontaal coördinatensysteem (X,Y) Rijksdriehoeksmeting (RD)
Verticale referentie (Z) Normaal Amsterdams Peil

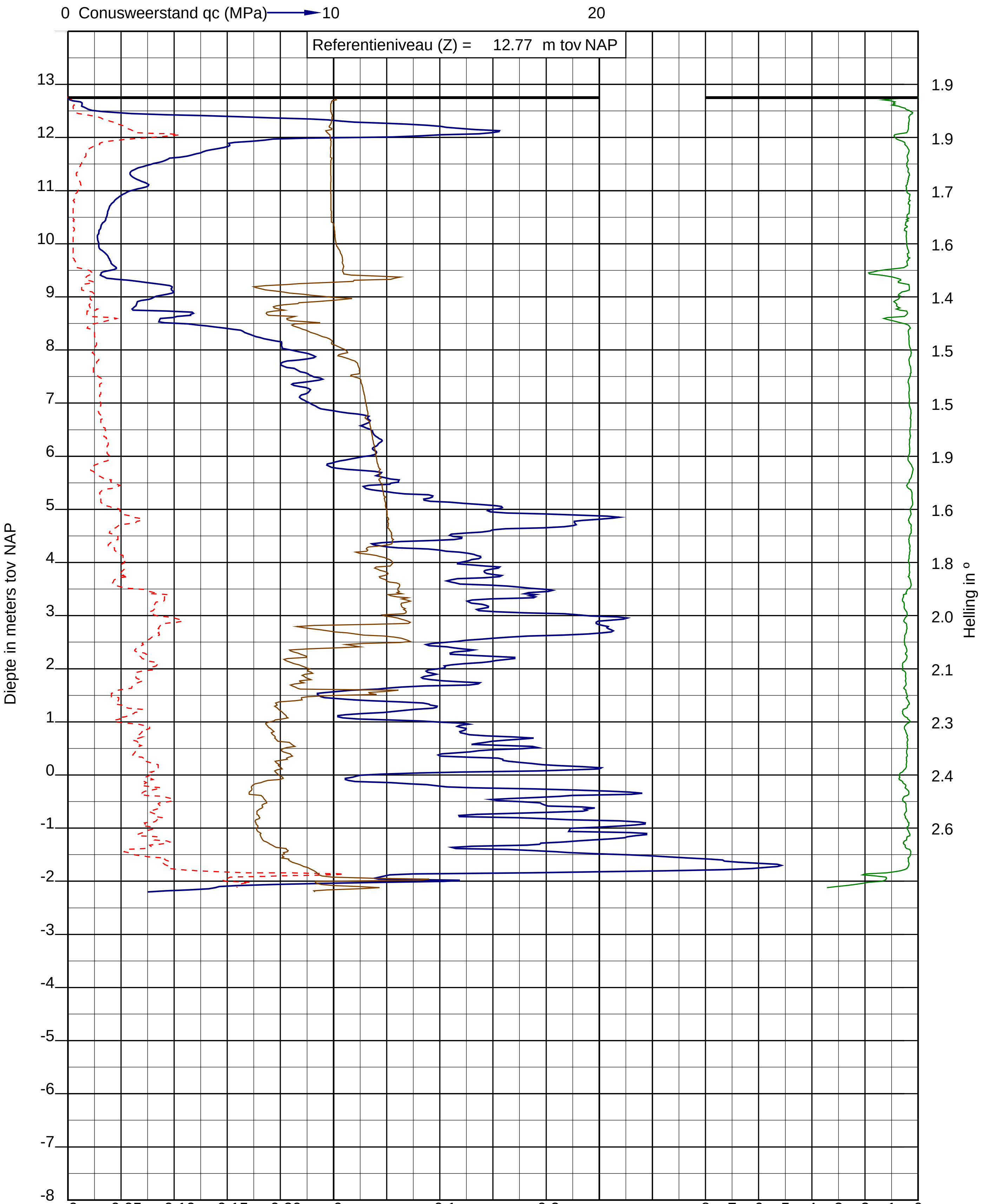
Meetpunt	X-coördinaat [m]	Y-coördinaat [m]	Hoogte (Z) [m t.o.v. NAP]	GWS * [m t.o.v. NAP]	Datum uitvoering
DKMP001	238890,51	472001,92	12,77	---	09-02-2023
DKMP002	238918,08	472014,33	11,72	9,53	09-02-2023
DKMP003	238910,20	471994,70	12,00	9,65	09-02-2023
DKMP004	238930,02	471986,80	11,64	---	09-02-2023
DKMP005	238902,99	471974,65	12,17	---	09-02-2023
DKMP005A	238902,99	471974,65	12,17	---	09-02-2023
Water001	238876,90	472021,00	9,89	---	09-02-2023
Weg001	238860,18	472000,18	12,87	---	09-02-2023

* Grondwaterstand ten tijde van het onderzoek

Let op:
Deze waterpasstaat dient om inzicht te geven in de hoogteligging en locaties van de meet- en onderzoeks-punten ten opzichte van een referentiepunt. Grondwaterstanden zijn ter indicatie en kunnen beïnvloed zijn door de uitgevoerde werkzaamheden. De resultaten dienen niet voor andere doeleinden te worden gebruikt.

BIJLAGE C
Sondeergrafieken

Project: Nieuwbouw nabij de Kanaalweg 2 te Markelo
Opdracht: 23ZP0171
Betreft: Sondeergrafiek

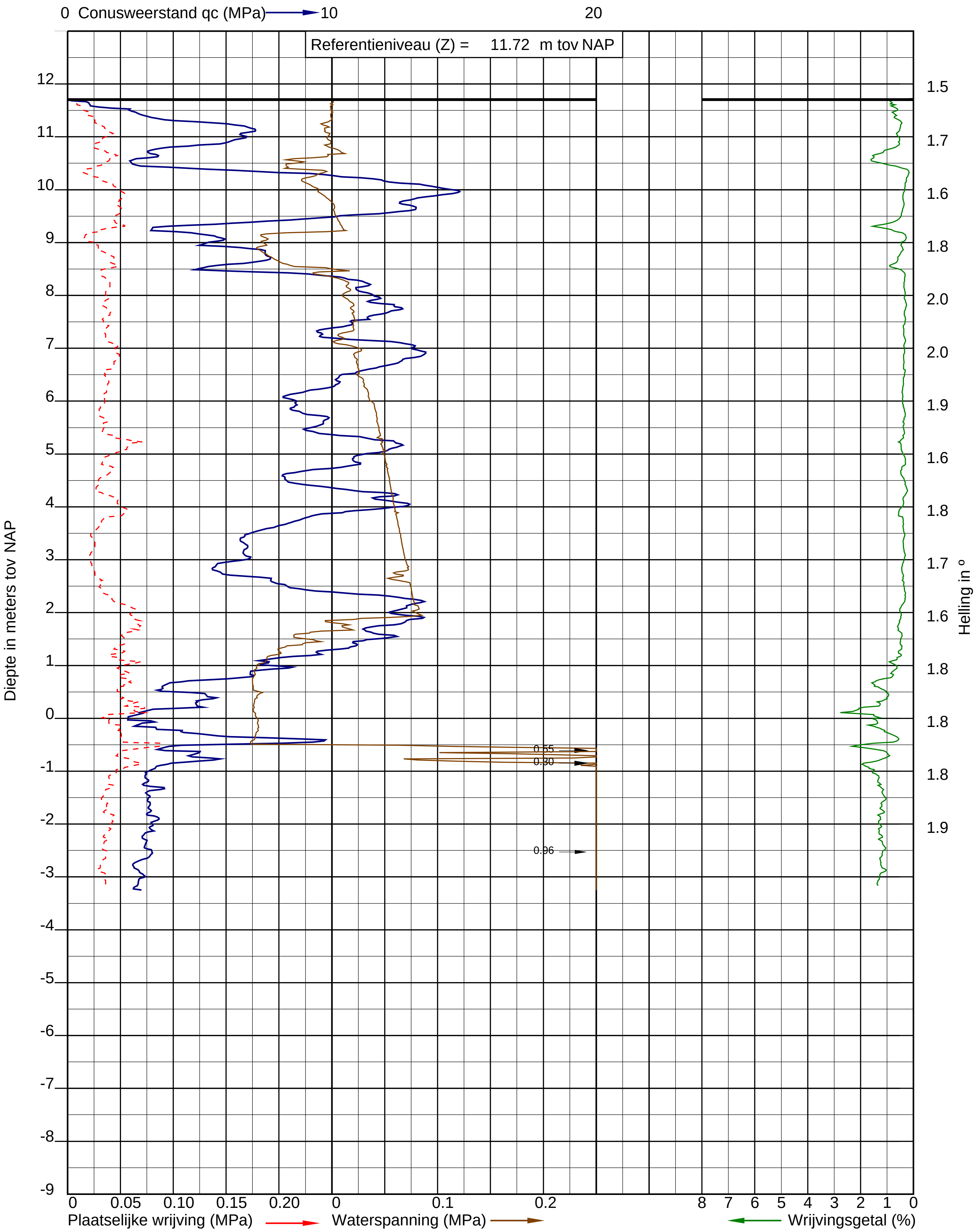


Uitvoeringsdatum: 9-2-2023
Norm: NEN-EN-ISO 22476-1
Toepassingsklasse: 3
Conusnummer: 060302

X: 238890.5
Y: 472001.9

DKMP001

Project: Nieuwbouw nabij de Kanaalweg 2 te Markelo
Opdracht: 23ZP0171
Betreft: Sondeergrafiek



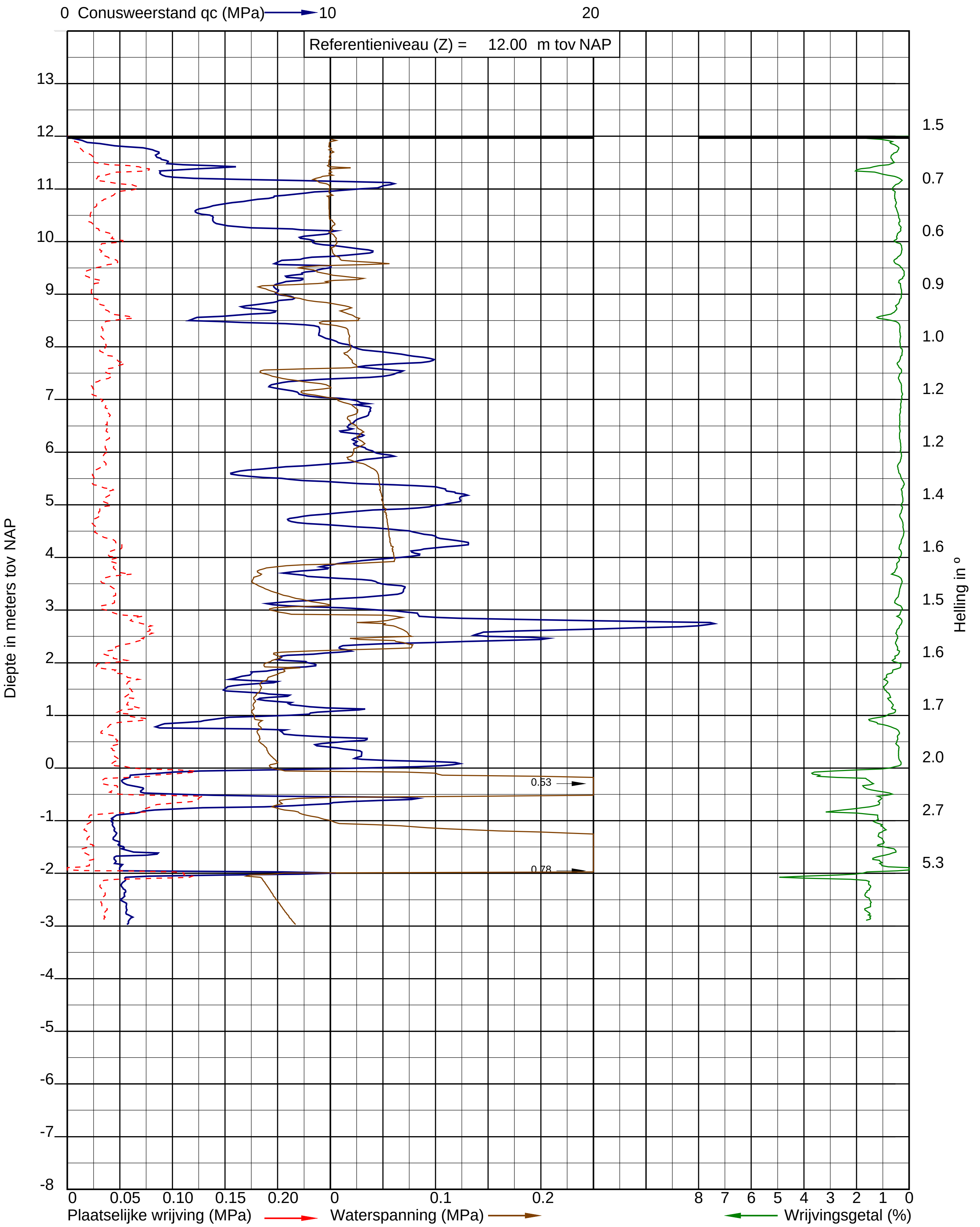
Uitvoeringsdatum: 9-2-2023
Norm: NEN-EN-ISO 22476-1
Toepassingsklasse: 3
Conusnummer: 060302

X: 238918.1
Y: 472014.3
GWS (m-mv): 2.20

DKMP002

INPIJN BLOKPOEL INGENIEURS

Project: Nieuwbouw nabij de Kanaalweg 2 te Markelo
Opdracht: 23ZP0171
Betreft: Sondeergrafiek

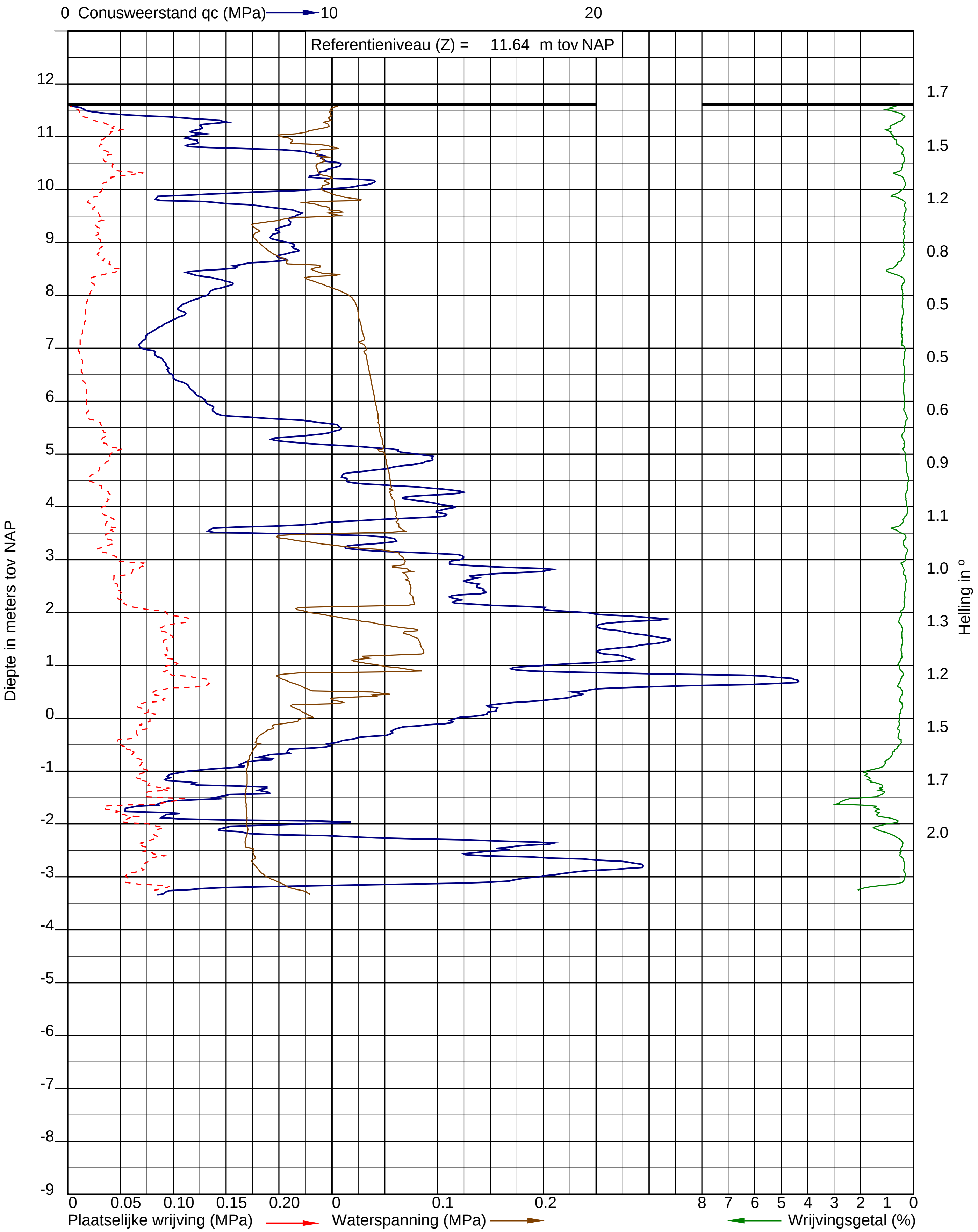


Uitvoeringsdatum: 9-2-2023
Norm: NEN-EN-ISO 22476-1
Toepassingsklasse: 3
Conusnummer: 060302

X: 238910.2
Y: 471994.7
GWS (m-mv): 2.35

DKMP003

Project: Nieuwbouw nabij de Kanaalweg 2 te Markelo
Opdracht: 23ZP0171
Betreft: Sondeergrafiek

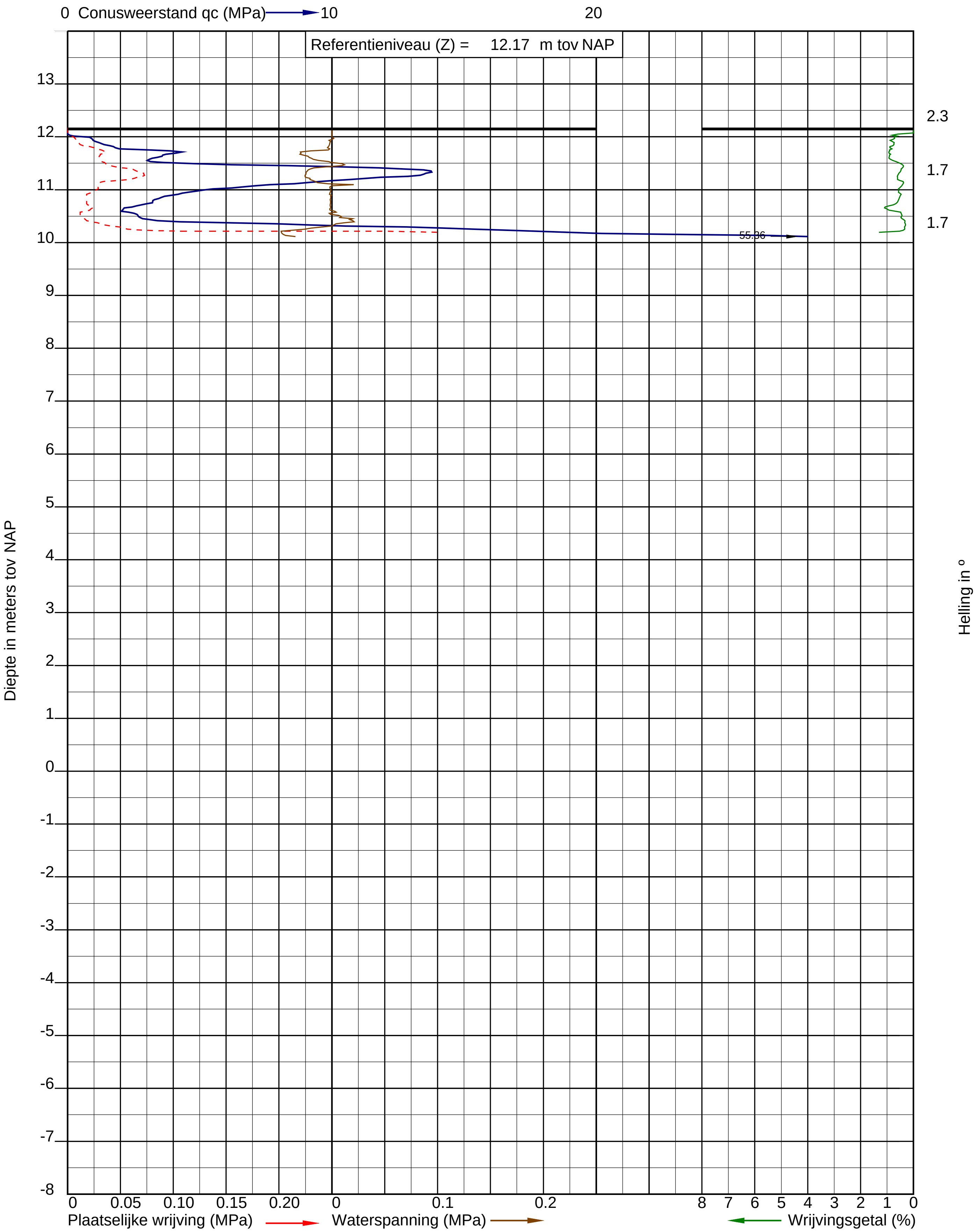


Uitvoeringsdatum: 9-2-2023
Norm: NEN-EN-ISO 22476-1
Toepassingsklasse: 3
Conusnummer: 060302

X: 238930.0
Y: 471986.8

DKMP004

Project: Nieuwbouw nabij de Kanaalweg 2 te Markelo
Opdracht: 23ZP0171
Betreft: Sondeergrafiek

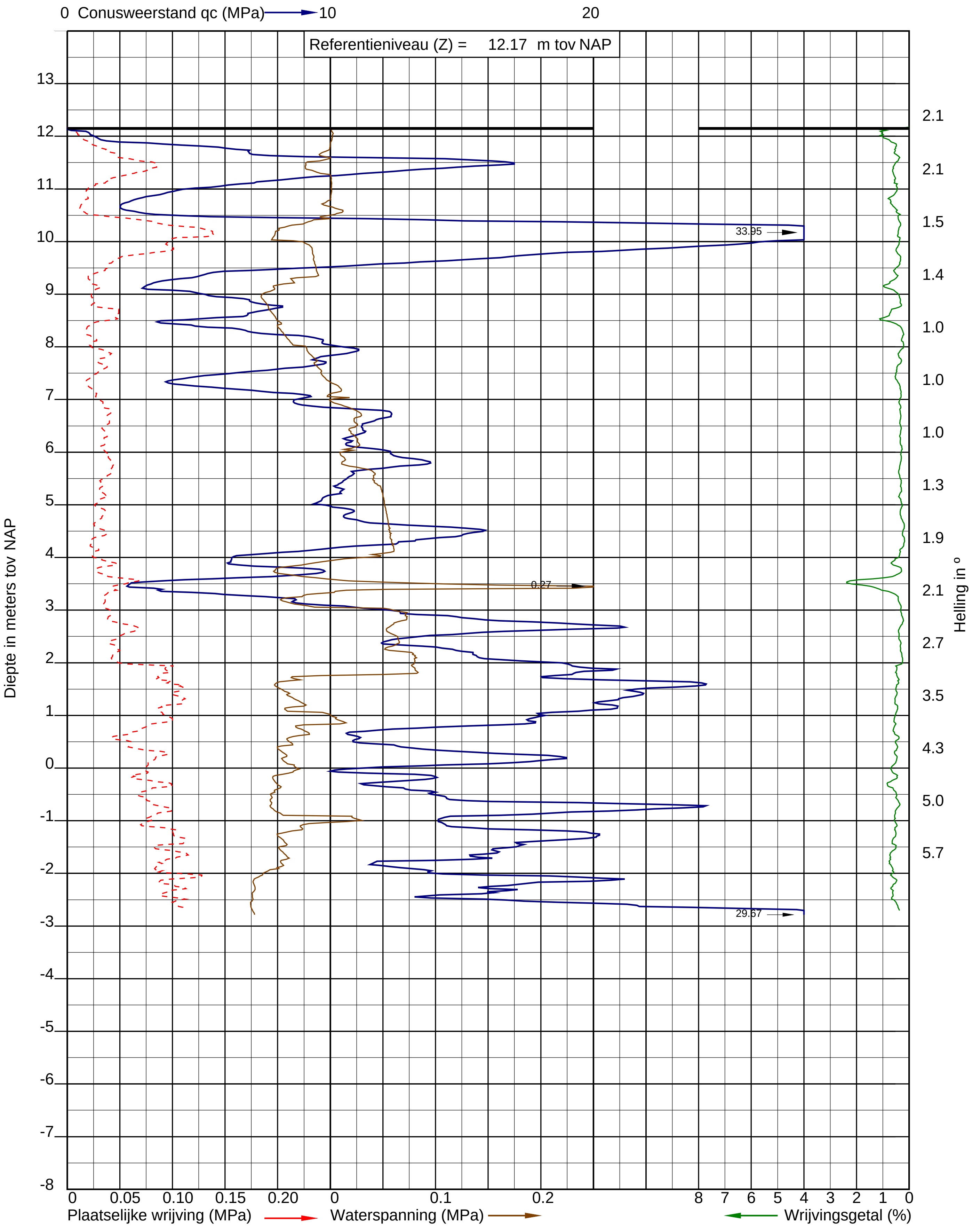


Uitvoeringsdatum: 9-2-2023
Norm: NEN-EN-ISO 22476-1
Toepassingsklasse: 3
Conusnummer: 060302

X: 238903.0
Y: 471974.7

DKMP005

Project: Nieuwbouw nabij de Kanaalweg 2 te Markelo
Opdracht: 23ZP0171
Betreft: Sondeergrafiek

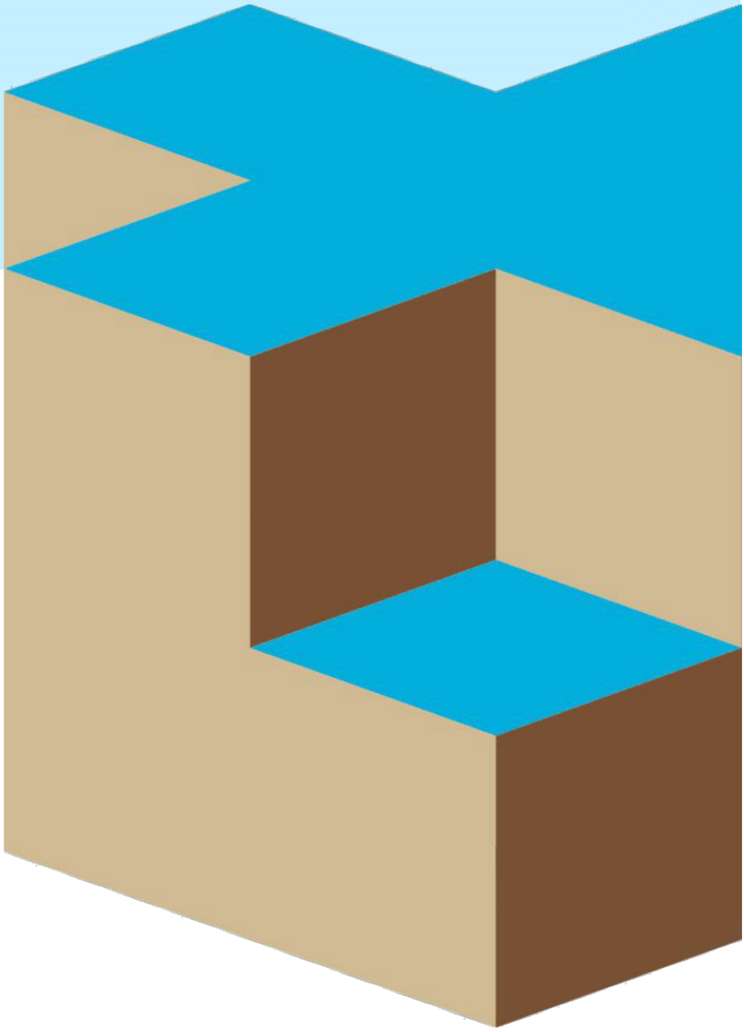


Uitvoeringsdatum: 9-2-2023
Norm: NEN-EN-ISO 22476-1
Toepassingsklasse: 3
Conusnummer: 060302

X: 238903.0
Y: 471974.7

DKMP005A

BIJLAGE D
Verklaring codering



LEGENDA TEKENINGEN EN VERKLARING AFKORTINGEN

SONDERING

▼ DKM Sondering met kleefmeting
DKMP Sondering met kleef- en waterspanningsmeting
DM Mechanische sondering
DKMS Seismische sondering
DKMSP Seismische sondering met waterspanningsmeting
DMa Magnetometer sondering
Ma Magnetometer (zonder conusweerstand)
DB Bolsondering
DT T-bar sondering
FVT Field vane test
HPT Hydraulic profiling tool
DS Slagsondering
HM Handsondering
SPT Standaard penetratie test
DKM-EC Geleidbaarheidssondering
DKMP-EC Geleidbaarheidssondering met waterspanningsmeting

▽ Niet uitgevoerd ▼ fase 2 ▼ fase 3 ▼ fase 4

BORING

● HB Handboring
B Mechanische boring

○ Niet uitgevoerd

PEILBUIS

PB Peilbuis
HBpb Handboring met peilbuis
Bpb Mechanische boring met peilbuis

PB Peilbuis met diver

MONITORING

WSM Waterspanningsmeter
IMB Inclinometerbuis
IMS Inclinometer SAAF
ZB Zakbaak
DB Deformatiebout
NAP Hoogtemeting
SCM Scheurmeter
TM Tiltmeter
TRM Trillingmeter
PDPs Plaatdrukproef (statisch)
PDPd Plaatdrukproef (dynamisch)
PRP Proefput
PRS Proefsleuf

ALGEMEEN

Meetpunt: brug, dorpel, kolk, meetbout, put, weg, water
F000 Foto
Bestaande bebouwing
0-Punt lokaal assenstelsel

VERKLARING CODERING BORINGEN
(conform NEN 5104)

GRIND
- grind, siltig
- grind, zwak zandig
- grind, matig zandig
- grind, sterk zandig
- grind, uiterst zandig

ZAND
- zand, kleiig
- zand, zwak siltig
- zand, matig siltig
- zand, sterk siltig
- zand, uiterst siltig

VEEN
- veen, mineraalarm
- veen, zwak kleiig
- veen, sterk kleiig
- veen, zwak zandig
- veen, sterk zandig

LEEM
- leem, zwak zandig
- leem, sterk zandig

SLIB
- slib

KLEI
- klei, zwak siltig
- klei, matig siltig
- klei, sterk siltig
- klei, uiterst siltig
- klei, zwak zandig
- klei, matig zandig
- klei, sterk zandig

TOEVOEGINGEN
- zwak humeus
- matig humeus
- sterk humeus
- zwak grindig
- matig grindig
- sterk grindig

PEILBUIS
- blinde buis
- casing
- indicatie hoge grondwaterstand
- actuele grondwaterstand
- indicatie lage grondwaterstand
- bentoniet afdichting
- filter

GRONDMONSTERS
- geroerd monster
- ongeroerd monster

OVERIG
- bijzonder bestanddeel
- indicatie hoge grondwaterstand
- actuele grondwaterstand
- indicatie lage grondwaterstand

11.2 Appendix B – Points baseline measurement

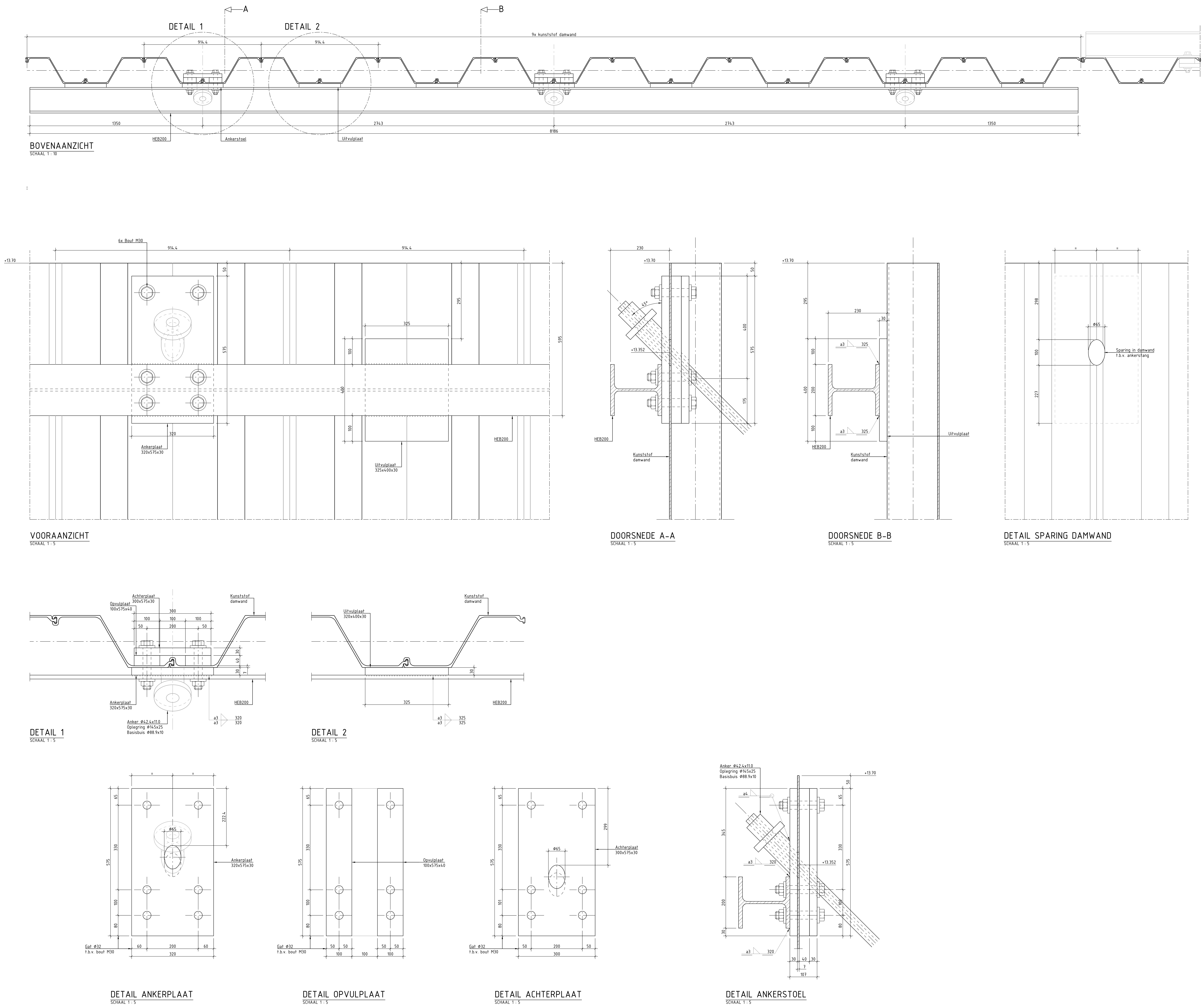
(nulmeting_1)

NULMETING	x [mm]	y [mm]	z [mm]	Time and date
1	55111	10456	895	13-6-2023 12:11
2	55112	10486	3175	13-6-2023 12:12
3	57821	10416	856	13-6-2023 12:12
4	57834	10467	3172	13-6-2023 12:12
5	60561	10406	853	13-6-2023 12:12
6	60561	10446	3173	13-6-2023 12:12
11	68779	10477	894	13-6-2023 12:13
12	68786	10500	3185	13-6-2023 12:14
13	71516	10468	936	13-6-2023 12:14
14	71531	10499	3171	13-6-2023 12:14
15	74252	10483	846	13-6-2023 12:14
16	74253	10494	3177	13-6-2023 12:14
21	79754	10489	853	13-6-2023 12:15
22	79752	10485	3204	13-6-2023 12:15
23	82490	10465	900	13-6-2023 12:15
24	82493	10503	3192	13-6-2023 12:15
25	85228	10473	888	13-6-2023 12:16
26	85232	10514	3177	13-6-2023 12:16

Table 11-1: Baseline measurement

11.3 Appendix C – Drawings

OTK-TM-4.1.3-TEK-9002 - Kunststof damwand - Ankerstoel en ankergording - Optie 1
OTK-TM-4.1.3-TEK-9003 - Kunststof damwand - Ankerstoel en ankergording - Optie 2
OTK-TM-4.1.3-TEK-9004 - Kunststof damwand - Ankerstoel en ankergording - Optie 3
OTK-TM-4.1.3-TEK-9005 - Proeftuin inrichting
OTK-TM-4.1.3-TEK-9006 - Proeftuin monitoringsplan ontgravingsproces
OTK-TM-4.1.3-TEK-9007 - Proeftuin monitoringsplan vijzelproces



BIJBEHORENDE TEKENINGEN

OTK-TM-4.1.3-TEK-9002	Optie 1
OTK-TM-4.1.3-TEK-9003	Optie 2
OTK-TM-4.1.3-TEK-9004	Optie 3
OTK-TM-4.1.3-TEK-9005	Inrichting
OTK-TM-4.1.3-TEK-9006	Monitoringsplan ontgravingsproces
OTK-TM-4.1.3-TEK-9007	Monitoringsplan vijzelproces

UITGANGSPUNTEN

Staalkwaliteit S355
Lassen EXC2
Bouten, moeren en sluit-/volg ringen toepassen bij alle boutverbindingen
Thermisch verzinkt klasse 8.8 voor alle bevestigingsmiddelen

ALGEMEEN

Hoeken in 360 graden stelsel
Maten in millimeters, tenzij anders aangegeven
Peilmaten in meters t.o.v. N.A.P.

Revisie:	Omschrijving:	Datum:	Opsteller:	Akkoord:
0.3	Concept	11-05-2023	MLE	
0.2	Concept	17-04-2023	MLE	
0.1	Concept	14-04-2023	MLE	

Hakkers | Beens Geïntegreerde projecten | Van Oord Marine ingenuity
Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Opwaardering Twentekanalen

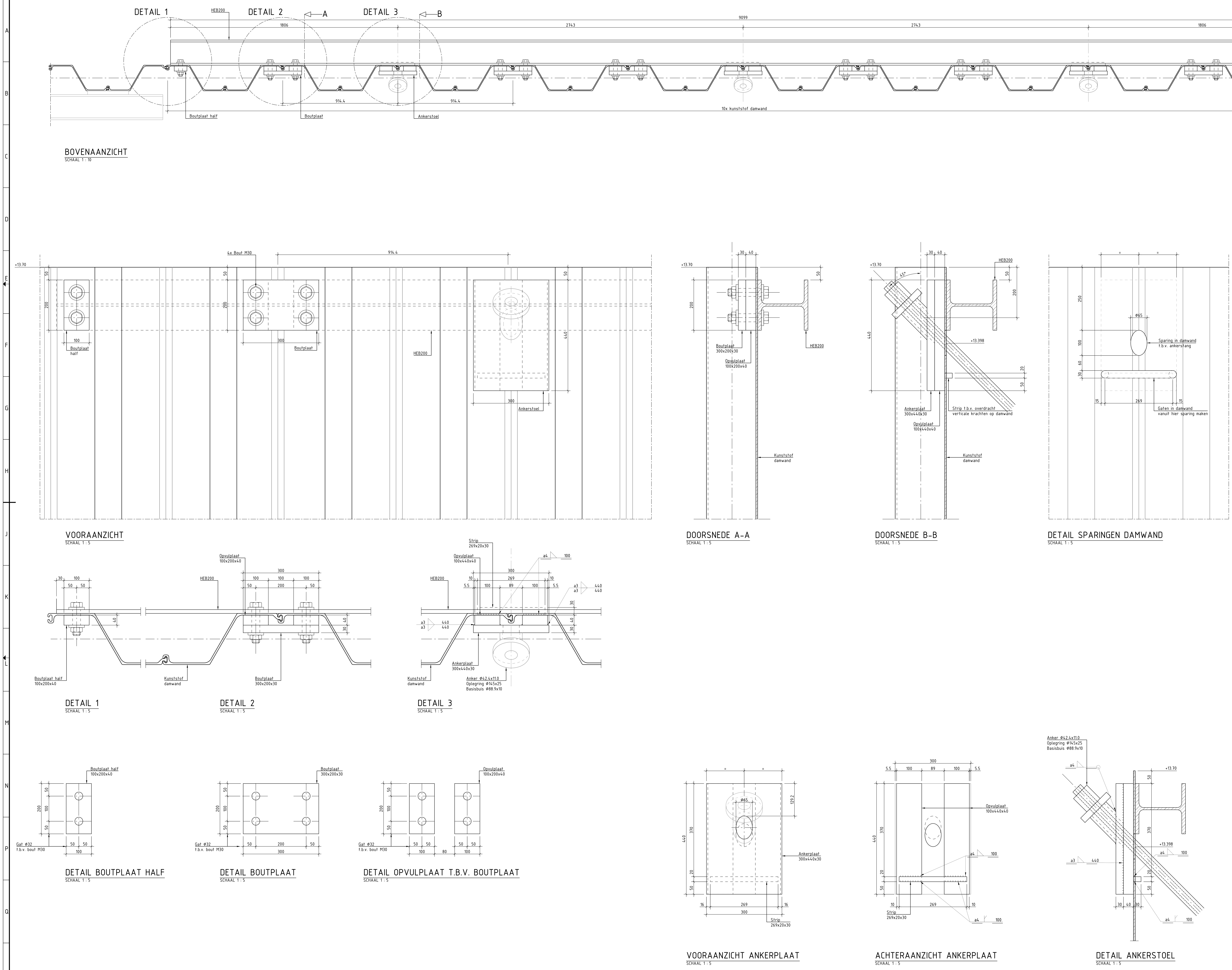
Rijkswaterstaat

Uitvoeringsontwerp
Proeftuin kunststof damwand
Optie 1

bedrijfsnummer XXX
zaaknummer 31142017
jaar 2023
formaat A0 schaal zie tek.

opsteller	Michiel van der Leeden	werkpakket 4.1.3		SBS
gecontroleerd ontwerpleider	Thom van Doremaele	blad 1 in 1 bladen		teknr OTK-TM-4.1.3-TEK-9002
vrijgave ontwerpmanager	Joël Sinke	status Concept	versie 0.3	docnr

T:\HWOT\04 Tekeningen\3. UO\Proeftuin Kunststof damwand\OTK-TM-4.1.3-TEK-9002 - Kunststof damwand - Optie 1.dwg



BIJBEHORENDE TEKENINGEN

OTK-TM-4.1.3-TEK-9002	Optie 1
OTK-TM-4.1.3-TEK-9003	Optie 2
OTK-TM-4.1.3-TEK-9004	Optie 3
OTK-TM-4.1.3-TEK-9005	Inrichting
OTK-TM-4.1.3-TEK-9006	Monitoringsplan ontgravingsproces
OTK-TM-4.1.3-TEK-9007	Monitoringsplan vijzelproces

UITGANGSPUNTEN

Staalkwaliteit S355
Lassen EXC2
Bouten, moeren en sluit-/volg ringen toepassen bij alle boutverbindingen
Thermisch verzinkt klasse 8.8 voor alle bevestigingsmiddelen

ALGEMEEN

Hoeken in 360 graden stelsel
Maten in millimeters, tenzij anders aangegeven
Peilmaten in meters t.o.v. N.A.P.

Revisie:	Omschrijving:	Datum:	Opsteller:	Akkoord:
0.3	Concept	11-05-2023	MLE	
0.2	Concept	17-04-2023	MLE	
0.1	Concept	14-04-2023	MLE	

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Opwaardering Twentekanalen

Rijkswaterstaat

Uitvoeringsontwerp
Proeftuin kunststof damwand
Optie 2

bedrijfsnummer	XXX
zaaknummer	31142017
jaar	2023
formaat	A0
schaal	zie tek.
opsteller	Michiel van der Leeden
gecontroleerd ontwerpleider	Thom van Doremaele
vrijgave ontwerpmanager	Joël Sinke
werkpakket	4.1.3
blad	1 in 1 bladen
status	Concept
versie	0.3
SBS	
teknr	OTK-TM-4.1.3-TEK-9003
docnr	

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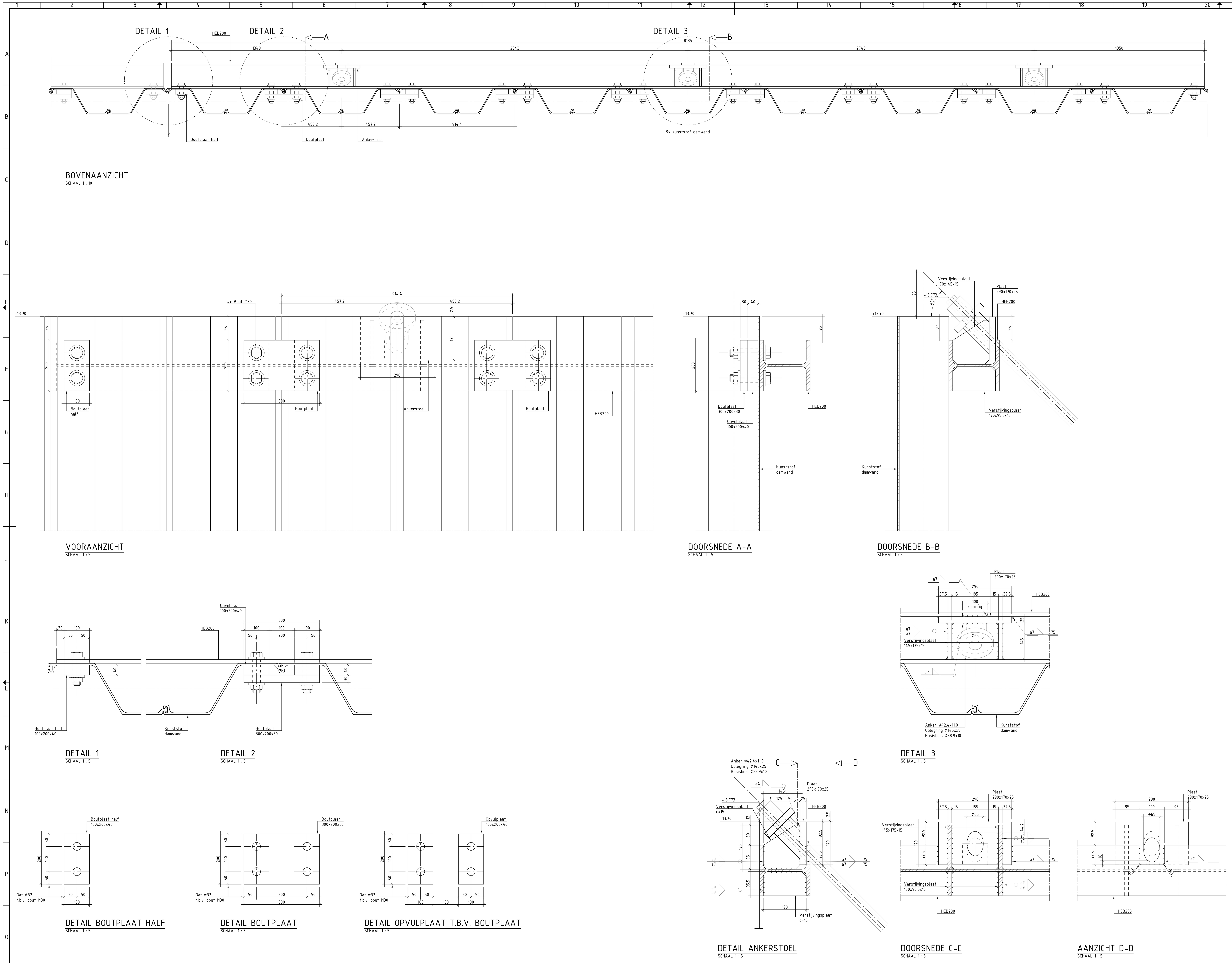

BIJBEHORENDE TEKENINGEN

OTK-TM-4.1.3-TEK-9002	Optie 1
OTK-TM-4.1.3-TEK-9003	Optie 2
OTK-TM-4.1.3-TEK-9004	Optie 3
OTK-TM-4.1.3-TEK-9005	Inrichting
OTK-TM-4.1.3-TEK-9006	Monitoringsplan ontgravingsproces
OTK-TM-4.1.3-TEK-9007	Monitoringsplan vijzelproces

UITGANGSPUNTEN

Staalkwaliteit S355
Lassen EXC2
Bouten, moeren en sluit-/volg ringen toepassen bij alle boutverbindingen
Thermisch verzinkt klasse 8.8 voor alle bevestigingsmiddelen

ALGEMEEN

Hoeken in 360 graden stelsel
Maten in millimeters, tenzij anders aangegeven
Peilmaten in meters t.o.v. N.A.P.

Revisie:	Omschrijving:	Datum:	Opsteller:	Akkoord:
0.3	Concept	11-05-2023	MLE	
0.2	Concept	17-04-2023	MLE	
0.1	Concept	14-04-2023	MLE	

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Opwaardering Twentekanalen

Rijkswaterstaat

Uitvoeringsontwerp
Proeftuin kunststof damwand
Optie 3

bedrijfsnummer	XXX		
zaaknummer	31142017		
jaar	2023		
formaat	A0	schaal	zie tek.
opsteller	Michiel van der Leeden	werkpakket	4.1.3
gecontroleerd ontwerpleider	Thom van Doremaele	blad 1 in 1 bladen	
vrijgave ontwerpmanager	Joël Sinke	status: Concept	versie: 0.3
SBS			
teknr	OTK-TM-4.1.3-TEK-9004		
docnr			

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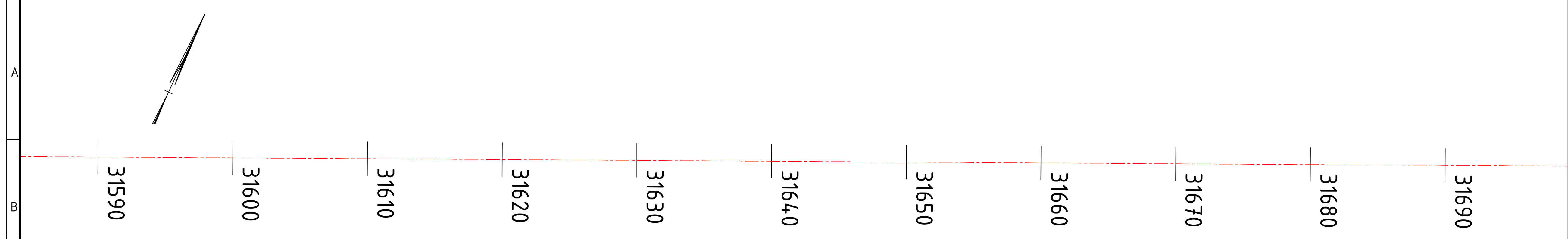


Tabel grondwerk

	Volume
Ontgraven	87m³
Aanvullen	174m³

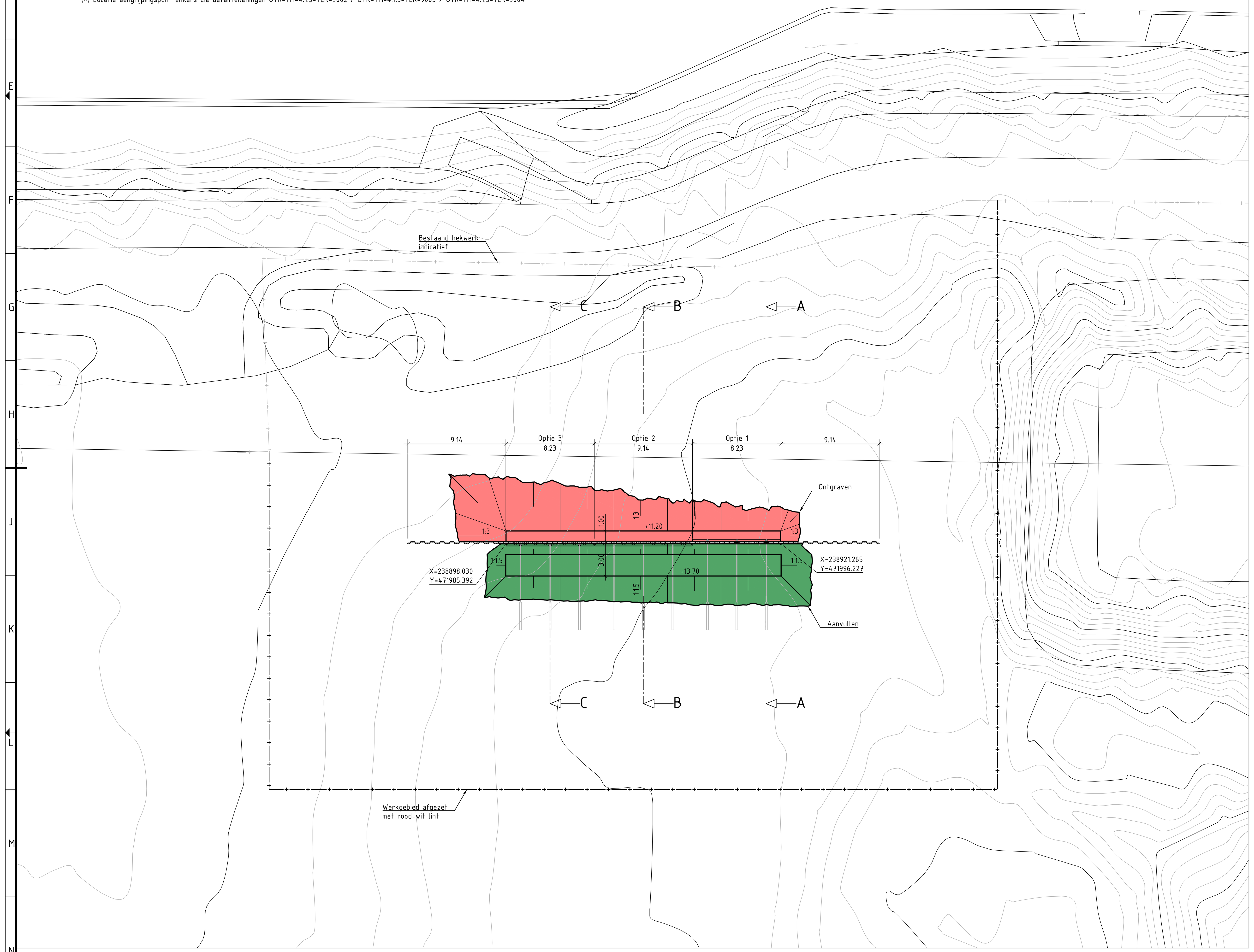
Damwandstaat

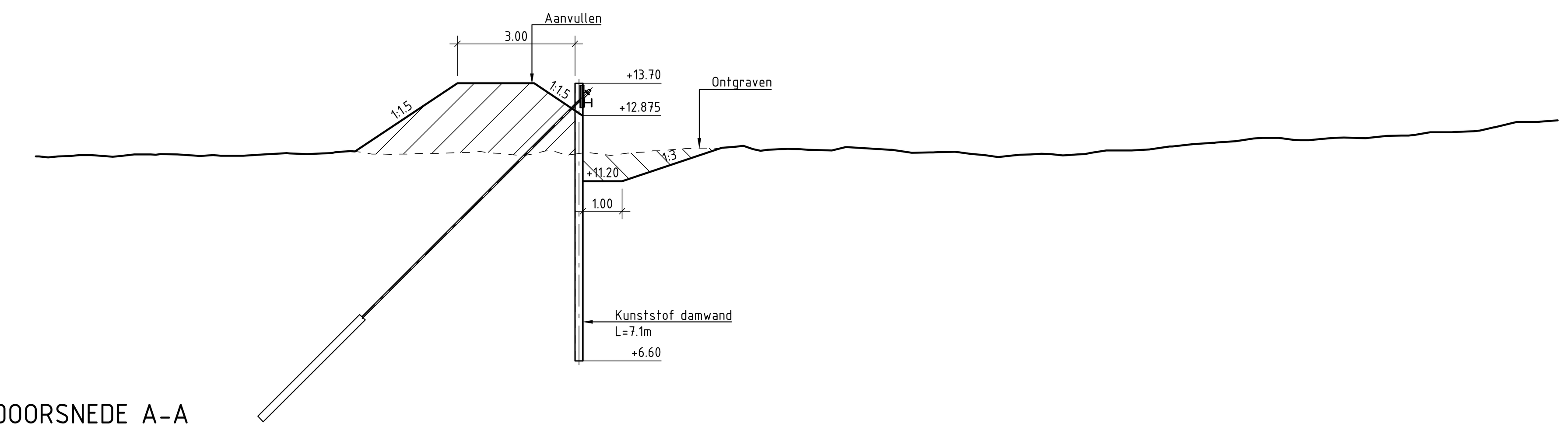
Type	Bovenkant [in m t.o.v. N.A.P.]	Onderkant [in m t.o.v. N.A.P.]	Lengte [in m]	Aantal
SS860D	+13.70	+6.60	7.10	48

Ankerstaat

Optie	Type	AGP (*) [in m t.o.v. N.A.P.]	L totaal [in m]	Bk grout [in m t.o.v. N.A.P.]	Ok grout [in m t.o.v. N.A.P.]	L grout [in m]	ØBoorkop [in mm]	ØGrout [in mm]	Hoek [in °]	Aantal
1	Φ42.4x11.0mm	+13.352	14	+8.00	+4.00	5.0	180	220	45	3
2	Φ42.4x11.0mm	+13.398	14	+8.00	+4.00	5.0	180	220	45	3
3	Φ42.4x11.0mm	+13.773	14	+8.00	+4.00	5.0	180	220	45	3

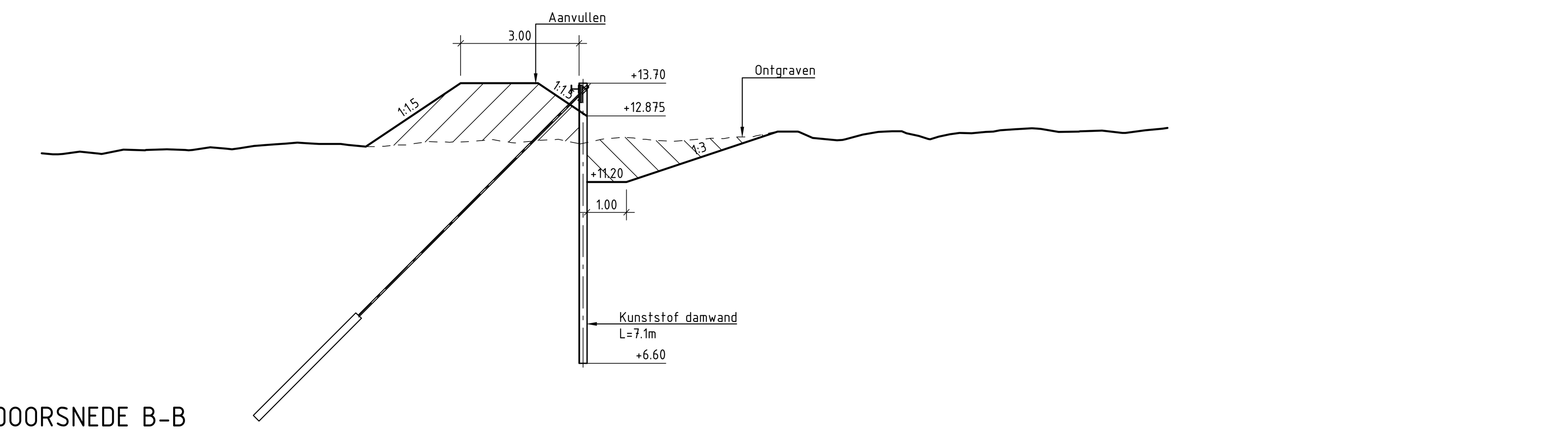
(*) Locatie aangrijpingspunt ankers zie detailtekeningen OTK-TM-4.1.3-TEK-9002 / OTK-TM-4.1.3-TEK-9003 / OTK-TM-4.1.3-TEK-9004





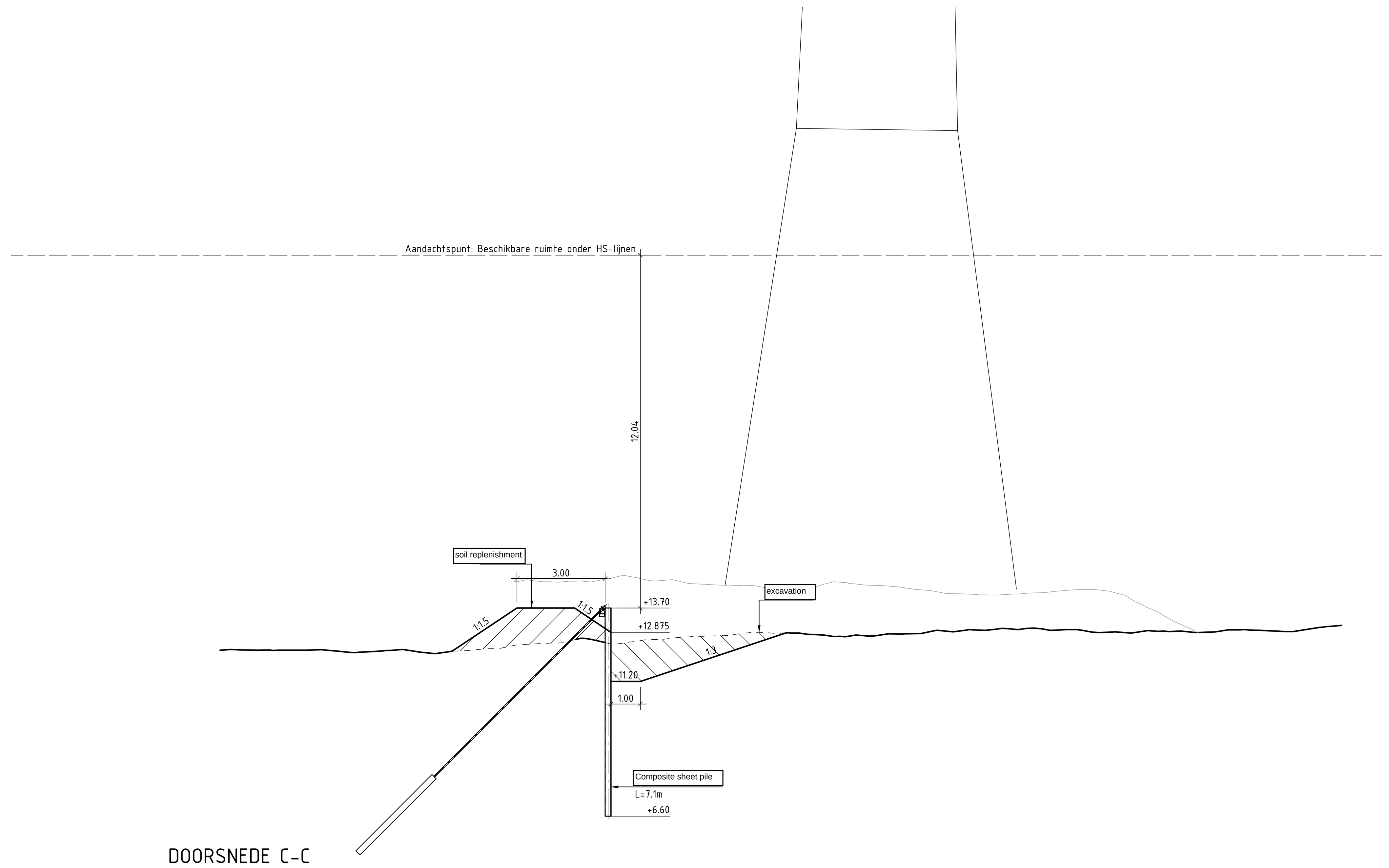
DOORSNEDE A-A

SCHAAL 1 : 100



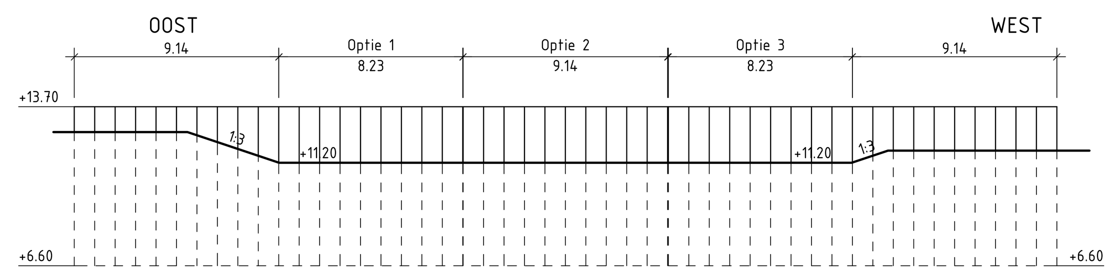
DOORSNEDE B-B

SCHAAL 1 : 100



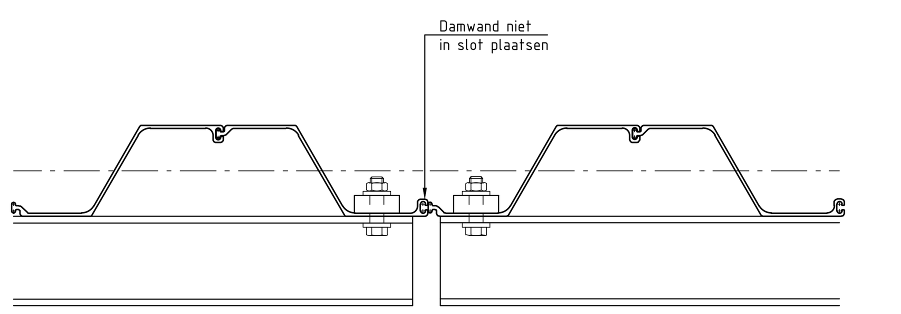
DOORSNEDE C-C

SCHAAL 1 : 100



VOORAANZICHT

SCHAAL 1 : 200



DETAIL OVERGANG DAMWAND TUSSEN OPTIES

SCHAAL 1 : 10

BIJBEHORENDE TEKENINGEN

OTK-TM-4.1.3-TEK-9002	Optie 1
OTK-TM-4.1.3-TEK-9003	Optie 2
OTK-TM-4.1.3-TEK-9004	Optie 3
OTK-TM-4.1.3-TEK-9005	Inrichting
OTK-TM-4.1.3-TEK-9006	Monitoringsplan ontgravingsproces
OTK-TM-4.1.3-TEK-9007	Monitoringsplan vijzelproces

ALGEMEEN

Hoeken in 360 graden stelsel
Maten in meters, tenzij anders aangegeven
Peilmaten in meters t.o.v. N.A.P.
Coördinaten in meters t.o.v. Rijksdriehoekstelsel

Revisie:	Omschrijving:	Datum:	Opsteller:	Akkoord:
0.3	Concept	17-05-2023	MLE	
0.2	Concept	11-05-2023	MLE	
0.1	Concept	14-04-2023	MLE	

Hakkers | Beens Geïntegreerde projecten | Van Oord

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Opwaardering Twentekanalen

Rijkswaterstaat

Uitvoeringsontwerp
Proeftuin kunststof damwand
I

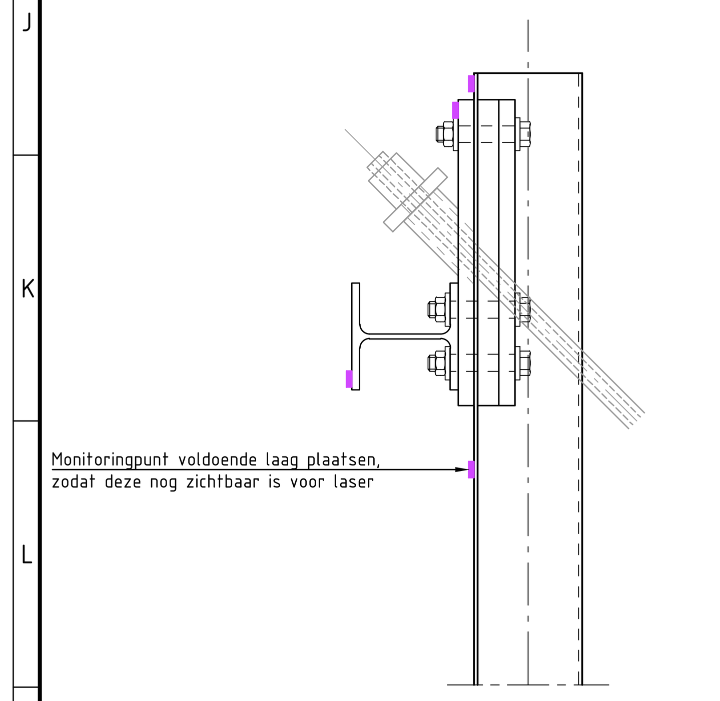
bedrijfsnummer XXX
zaaknummer 31142017
jaar 2023
formaat A0 schaal zie tek.

opsteller	Michiel van der	werkpakket 4.1.3	SBS
gecontroleerd ontwerpleider	Thom van Doremaele	blad 1 in 1 bladen	teknr OTK-TM-4.1.3-TEK-9005
vrijgave ontwerpmanager	Joël Sinke	status Concept / versie 0.3	docnr

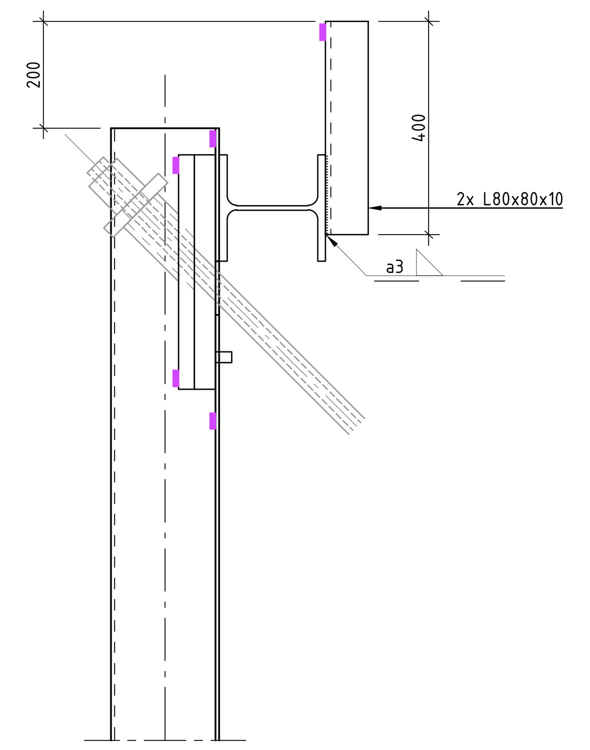
T:\HWOT\04 Tekeningen\3. UO\Proeftuin Kunststof damwand\OTK-TM-4.1.3-TEK-9005 - Kunststof damwand - inrichting.dwg

BOVENAANZICHT
SCHAAL 1 : 25

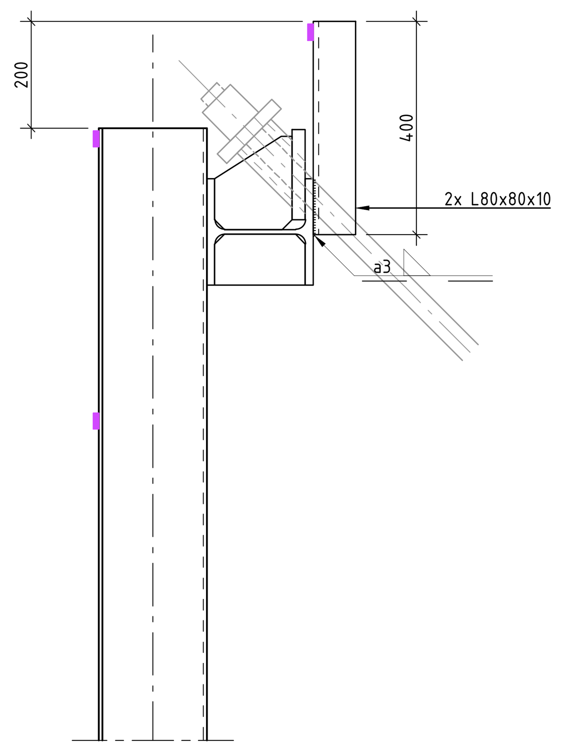
VOORAANZICHT
SCHAAL 1 : 25



DOORSNEDE A-A
SCHAAL 1 : 10



DOORSNEDE B-B
SCHAAL 1 : 10



DOORSNEDE C-C
SCHAAL 1 : 10

BIJBEHORENDE TEKENINGEN

OTK-TM-4.1.3-TEK-9002	Optie 1
OTK-TM-4.1.3-TEK-9003	Optie 2
OTK-TM-4.1.3-TEK-9004	Optie 3
OTK-TM-4.1.3-TEK-9005	Inrichting
OTK-TM-4.1.3-TEK-9006	Monitoringsplan ontgravingsproces
OTK-TM-4.1.3-TEK-9007	Monitoringsplan vijzelproces

LEGENDA

& Monitoringspunt per anker:
- Optie 1: 4x damwand, 2x ankerstoel, 2x ankergording
- Optie 2: 4x damwand, 4x ankerstoel, 2x hoekprofiel
- Optie 3: 4x damwand, 2x hoekprofiel

Kijkrichting camera

Revisie:	Omschrijving:	Datum:	Opsteller:	Akkoord:
0.2	Concept	13-04-2023	MLE	
0.1	Concept	07-04-2023	MLE	

Hakkers | Beens Geïntegreerde projecten | Van Oord Marine ingenuity
Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Opwaardering Twentekanalen

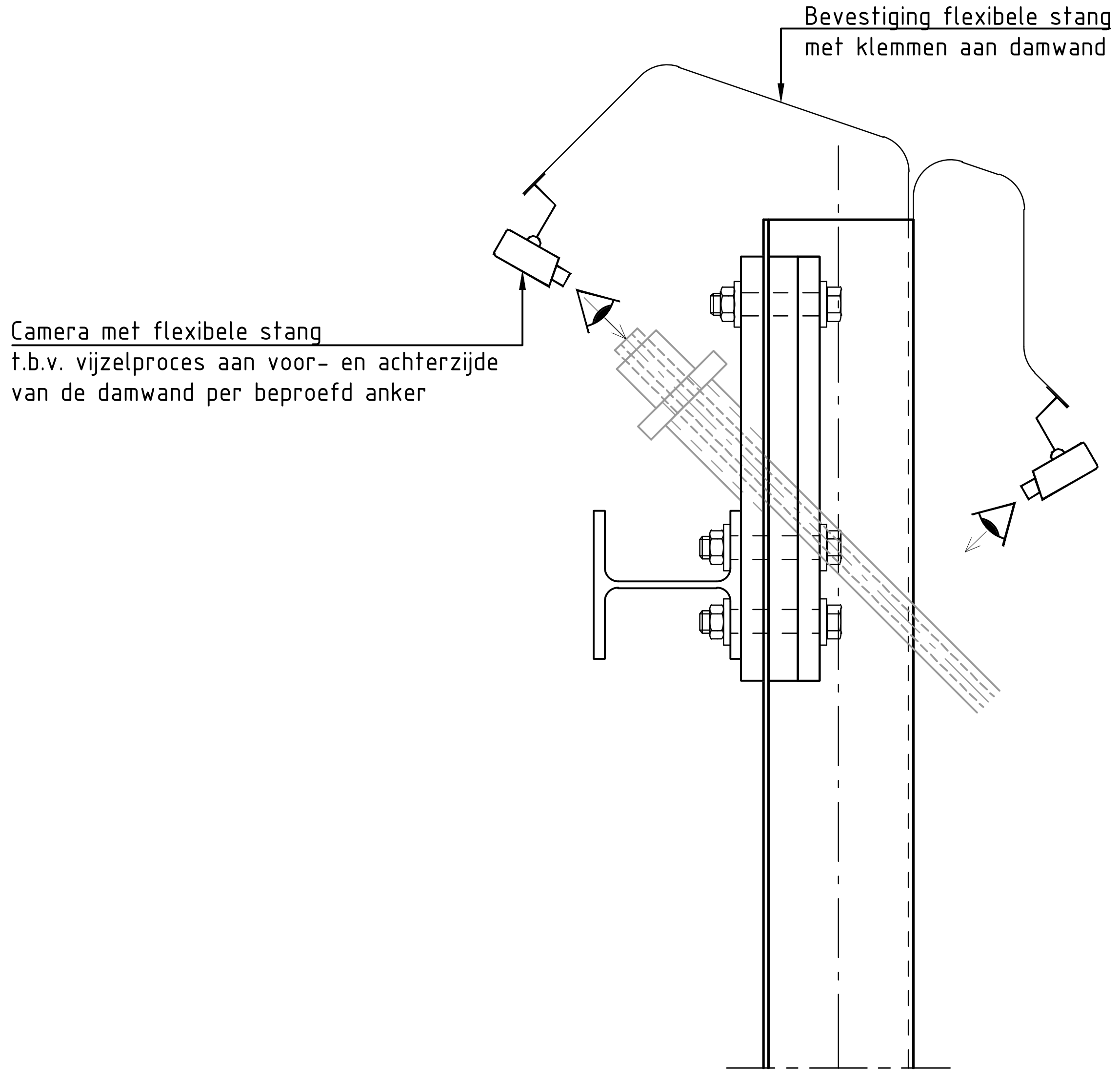
Rijkswaterstaat

Uitvoeringsontwerp
Proeftuin kunststof damwand
Monitoringsplan ontgravingsproces

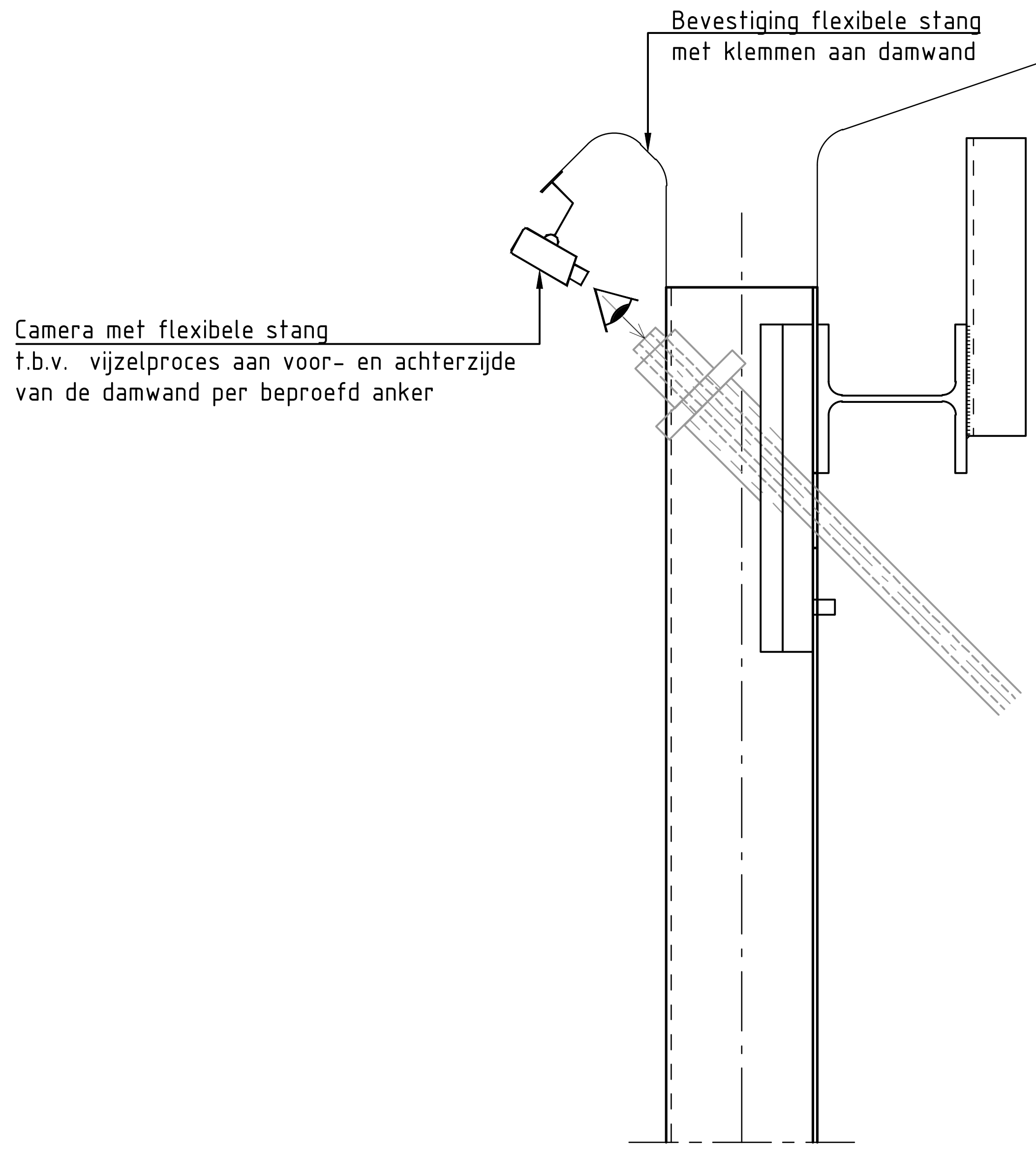
bedrijfsnummer XXX
zaaknummer 31142017
jaar 2023
formaat A1.0 schaal zie tek.

opsteller	Michiel van der Leeden	werkpakket 4.1.3	SBS
gecontroleerd ontwerpleider	Thom van Doremaele	blad 1 in 1 bladen	teknr OTK-TM-4.1.3-TEK-9006
vrijgave ontwerpmanager	Joël Sinke	status Concept / versie 0.2	docnr

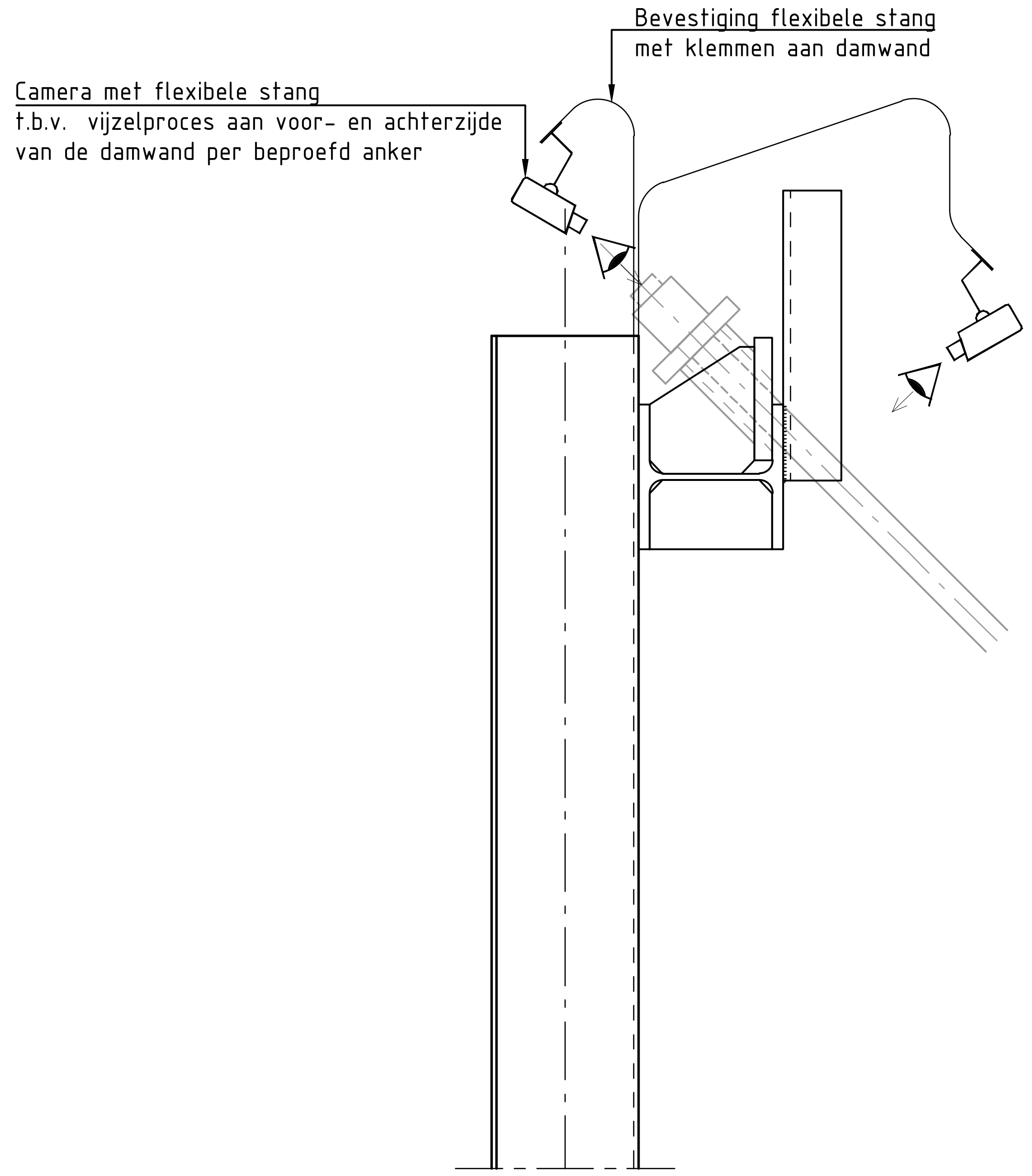
T:\HWOT\04 Tekeningen\3. UO\BIM360-B&S Proeftuin Kunststof damwand\OTK-TM-4.1.3-TEK-9006 - Kunststof damwand - Proeftuin monitoring ontgravingsproces.



DOORSNEDE T.P.V. OPTIE 1
SCHAAL 1 : 10



DOORSNEDE T.P.V. OPTIE 2
SCHAAL 1 : 10



DOORSNEDE T.P.V. OPTIE 3
SCHAAL 1 : 10

BIJBEHORENDE TEKENINGEN

OTK-TM-4.1.3-TEK-9002	Optie 1
OTK-TM-4.1.3-TEK-9003	Optie 2
OTK-TM-4.1.3-TEK-9004	Optie 3
OTK-TM-4.1.3-TEK-9005	Inrichting
OTK-TM-4.1.3-TEK-9006	Monitoringsplan ontgravingsproces
OTK-TM-4.1.3-TEK-9007	Monitoringsplan vijzelproces

LEGENDA

Kijkrichting camera

Revisie:	Omschrijving:	Datum:	Opsteller:	Akkoord:
0.1	Concept	13-04-2023	MLE	

Hakkers | Beens Geïntegreerde projecten | Van Oord

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Opwaardering Twentekanalen

Rijkswaterstaat

Uitvoeringsontwerp
Proeftuin kunststof damwand
Monitoringsplan vijzelproces

bedrijfsnummer XXX
zaaknummer 31142017
jaar 2023
formaat A2 schaal zie tek.

opsteller	Michiel van der Leeden	werkpakket 4.1.3	SBS
gecontroleerd ontwerpleider	Thom van Doremaele	blad 1 in 1 bladen	teknr OTK-TM-4.1.3-TEK-9007
vrijgave ontwerpmanager	Joël Sinke	status Concept / versie 0.1	docnr

T:\HWOT\04 Tekeningen\3. UO\BIM360-B&S Proeftuin Kunststof damwand\OTK-TM-4.1.3-TEK-9007 - Kunststof damwand - Proeftuin monitoring vijzelproces.dwg

11.4 Appendix D – Design Jetmix

Jetmix FUNDERINGSTECHNIEK

Project 20.043 OTK
Opdrachtgever Combinatie OTK
Onderdeel
Versie 1,1
Datum 14-04-2023

Rekensheet versie 2.5 d.d. 17-10-2018
Op bais van CUR166 6e druk juli 2012

Totaaloverzicht/samenvatting ankerontwerp

Doorsnede	Sondering	Ontwerp-nummer	Ankertype	Damwandtype (en -kwaliteit)	$L_{praktisch}$ Incl. overlengte	$L_{theoretisch}$ excl. overlengte	hor. ruimte-beslag	Anker-niveau	BKgrout	OKgrout	L_{grout}	$Ø_{boorkop/-kroon}$	$Ø_{grout}$	Anker-hoek tov hor.	Anker-hoek tov vert.	H.o.h. afstand	$L_{traject}$	Aantal ankers	P_{test}	P_{vsp}
DKMP001	DKMP001	01	Ø 42,4x11,0	AZ-12-700	13,00	12,35	8,74	+ 12,20	+ 7,00	+ 3,46	5,00	180	220	45	0	2,75	0,00	0	440	100
DKMP002	DKMP002	02	Ø 42,4x11,0	AZ20-700	13,00	12,57	8,89	+ 12,20	+ 7,00	+ 3,31	5,22	180	220	45	0	2,75	0,00	0	440	100
DKMP003	DKMP003	03	Ø 42,4x11,0	AZ12-700	13,00	12,35	8,74	+ 12,20	+ 7,00	+ 3,46	5,00	180	220	45	0	2,75	0,00	0	440	100
DKMP004	DKMP004	04	Ø 42,4x11,0	AZ12-700	14,00	12,99	9,19	+ 12,20	+ 7,00	+ 3,01	5,64	180	220	45	0	2,75	0,00	0	440	100
DKMP005	DKMP005A	05	Ø 42,4x11,0	AZ12-700	13,00	12,35	8,74	+ 12,20	+ 7,00	+ 3,46	5,00	180	220	45	0	2,75	0,00	0	440	100
Totaal																	**0,00**	**0**		

Doorsnede: DKMP004 DKMP004 Ontwerpnr. 04

Project	20.043 OTK	**Rekensheet versie 2.5 d.d. 17-10-2018**
Opdrachtgever	Combinatie OTK	
Onderdeel		
Versie	1,1	
Datum	14-04-2023	

Te verankeren constructie

Damwandtype	:	AZ12-700	Trajectlengte	:	0,00 m^1
Bovenzijde wand	:	+ 0,00 m NAP	Aantal secties = $L_{traject}$ / hoh_{reg}	=	0,00 st
Onderzijde wand	:	+ 0,00 m NAP	Praktisch aantal ankers	:	0 st
Ankerniveau	:	+ 12,20 m NAP			

Belastingen

Hoek tov hor. (D-sheet)	:	45 °				
$P_{max;ax;UGT}$ (D-sheet)	:	145 kN/m^1	-->	$P_{max;hor;UGT} = P_{max;ax;UGT} \times \cos(\alpha_h)$	=	103 kN/m^1
$P_{max;ax;BGT}$ (D-sheet)	:	0 kN/m^1	-->	$P_{max;hor;BGT} = P_{max;ax;BGT} \times \cos(\alpha_h)$	=	0 kN/m^1
$P_{vsp;ax}$ Voorspanning (D-sheet)	:	36 kN/m^1	-->	$P_{vsp;hor} = P_{vsp;ax} \times \cos(\alpha_h)$	=	26 kN/m^1
α_h (Ankerhoek tov hor.)	:	45 °		Hart-op-hart afstand - regulier	:	2,75 m^1
α_v (Ankerhoek tov vert. (=offset))	:	0 °		Hart-op-hart afstand - ankeruitval	:	4,13 m^1
				(Ankeruitval= 1 anker)		

$E_{ULS,d} = hoh_{reg} \times P_{max,hor,UGT} / \cos(\alpha_h) / \cos(\alpha_v)$ = 400 kN

$E_{ULS,k} = hoh_{A.U.} \times P_{max,hor,BGT} / \cos(\alpha_h) / \cos(\alpha_v)$ = 0 kN

$P_{VSP} = hoh_{reg} \times P_{vsp;hor} / \cos(\alpha_h) / \cos(\alpha_v)$ = 100 kN

Anker

Ankersysteem	:	Zelfborend			
Ankertype	:	Ø 42,4x11,0	A_{staal} vóór corrosie	:	1038 mm^2
Corrosie	:	0,0000 mm/jaar	A_{staal} na corrosie	=	1038 mm^2
Levensduur	:	100 jaar	fy en fu worden gereduceerd met factor 1,016		
			conform CUR166-6e druk deel 2 par. 2.4.7		

Toets staal

$F_{tg;Rd} = (A_{staal} \times f_y) / (\gamma_{m0})$	=	511 kN	*conform NEN-EN-1993-5:2008 (7.2)*	f_y (vloei)	:	492 N/mm^2
$F_{tt;Rd} = (k_t \times A_{staal} \times f_u) / (\gamma_{m2})$	=	515 kN	*conform NEN-EN-1993-5:2008 (7.1)*	f_u (breuk)	:	689 N/mm^2
$R_{t;d} = MIN(F_{tg,Rd} ; F_{tt,Rd}) / (\gamma_{a,NL})$	=	409 kN	**Unity Check UGT -->**	**$E_{ULS,d} / R_{t;d}$**	=	**0,98 -**
$R_{t;k} = MIN(F_{tg,Rd} ; F_{tt,Rd})$	=	511 kN	**Unity Check BGT -->**	**$E_{ULS,k} / R_{t;k}$**	=	**0,00 -**

Toets groutlichaam

Maaiveld	:	+ 12,20 m NAP	α_t	:	0,0150 -
Bovenzijde zandlaag	:	+ 8,50 m NAP	Boorkop diameter	:	180 mm
Bovenzijde grout	:	+ 7,00 m NAP	Oppersing	:	40 mm
Check 5,00 m gronddekking	:	OK	Diameter groutlichaam	=	220 mm
Check h.o.h. afstand min. 8D	:	OK	Omtrek groutlichaam	=	0,691 m
Check 1,00 m zanddekking	:	OK			
L_{grout}	=	5,64 m			
QC_{gem}	=	9,24 MPa	Onderzijde grout	=	+ 3,01 m N.A.P.
$R_{ULS;d} = (\alpha_t \times O \times L_{grout} \times Q_{c;gem}) / \gamma_{a,ULS}$	=	400 kN ($\gamma_{a,ULS}$ = 1,35)	**Unity Check UGT**	=	**1,00 -**
$R_{SLS;d} = (\alpha_t \times O \times L_{grout} \times Q_{c;gem})$	=	540 kN	**Unity Check BGT**	=	**0,00 -**

Doorsnede:	**DKMP004**	**DKMP004**	**Ontwerpnr. 04**

Rekensheet versie 2.5 d.d. 17-10-2018

Project 20.043 OTK
Opdrachtgever Combinatie OTK
Onderdeel
Versie 1,1
Datum 14-04-2023

Bodemopbouw

Toegepaste sondering : DKMP004
Maaiveld : + 12,20 m NAP
Bovenzijde grout : + 7,00 m NAP

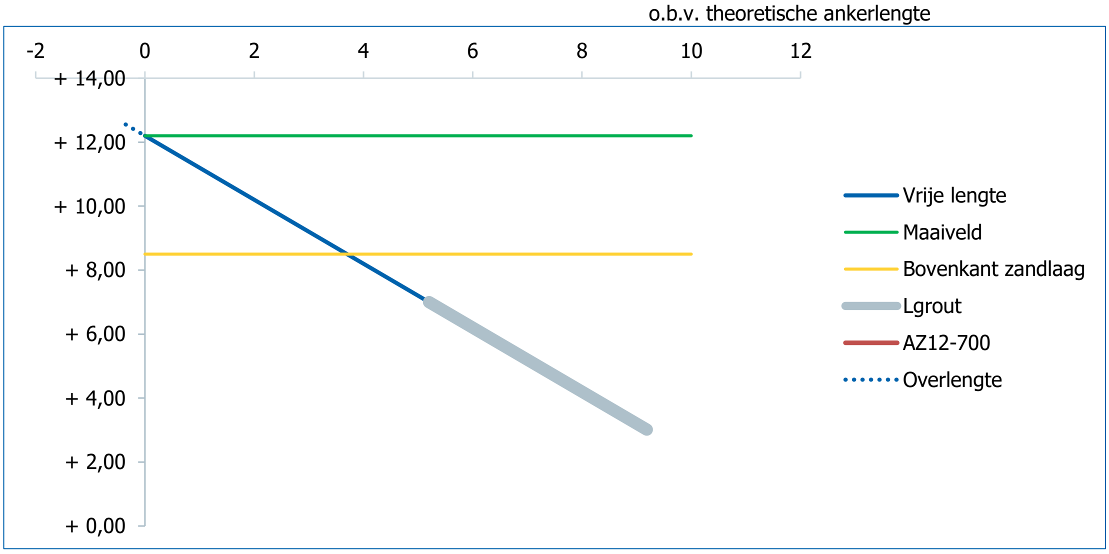
van	tot		QC	QC_{gem}	dR_d	dL_{grout}	R_d
[m N.A.P.]	[m N.A.P.]		[MPa]	[Mpa]	[kN]	[m]	[kN]
+ 7,00	+ 6,50		4,0	4	22	0,71	22
+ 6,50	+ 6,00		5,0	5	27	0,71	49
+ 6,00	+ 5,50		7,0	5	38	0,71	87
+ 5,50	+ 5,00		10,0	7	54	0,71	141
+ 5,00	+ 4,50		12,0	8	65	0,71	206
+ 4,50	+ 4,00		13,0	9	71	0,71	277
+ 4,00	+ 3,50		11,0	9	60	0,71	337
+ 3,50	+ 3,00		12,0	9	63	0,69	400
+ 3,00	+ 2,50		16,0	10	0	0,00	0
+ 2,50	+ 2,00		16,0	11	0	0,00	0
+ 2,00	+ 1,50		20,0	11	0	0,00	0
+ 1,50	+ 1,00		20,0	12	0	0,00	0
+ 1,00	+ 0,50		20,0	13	0	0,00	0
+ 0,50	+ 0,00		17,0	13	0	0,00	0
+ 0,00	- 0,50		12,0	13	0	0,00	0
- 0,50	- 1,00		7,0	13	0	0,00	0
- 1,00	- 1,50		5,0	12	0	0,00	0
- 1,50	- 2,00		5,0	12	0	0,00	0
- 2,00	- 2,50		12,0	12	0	0,00	0
- 2,50	- 3,00		19,0	12	0	0,00	0
- 3,00	- 3,50		10,0	12	0	0,00	0
- 3,50	- 4,00		0,0	12	0	0,00	0
- 4,00	- 4,50		0,0	11	0	0,00	0
- 4,50	- 5,00		0,0	11	0	0,00	0
- 5,00	- 5,50		0,0	10	0	0,00	0
- 5,50	- 6,00		0,0	10	0	0,00	0
- 6,00	- 6,50		0,0	9	0	0,00	0
- 6,50	- 7,00		0,0	9	0	0,00	0
- 7,00	- 7,50		0,0	9	0	0,00	0
- 7,50	- 8,00		0,0	8	0	0,00	0
Totaal					**400**	**5,64**	

Doorsnede: DKMP004 DKMP004 Ontwerpnr. 04

Project	20.043 OTK	**Rekensheet versie 2.5 d.d. 17-10-2018**
Opdrachtgever	Combinatie OTK	
Onderdeel		
Versie	1,1	
Datum	14-04-2023	

Bepaling ankerlengte

Vrije ankerlengte	=	7,35 m		Overlengte tbv ankerkop	:	0,50 m
Ankerlengte theoretisch	=	12,99 m		L_{app} fictieve ankerlengte	=	10,68 m
L_{totaal} (ankerlengte praktisch)	=	14,00 m		Horizontaal ruimtebeslag	=	9,19 m
				o.b.v. theoretische ankerlengte		



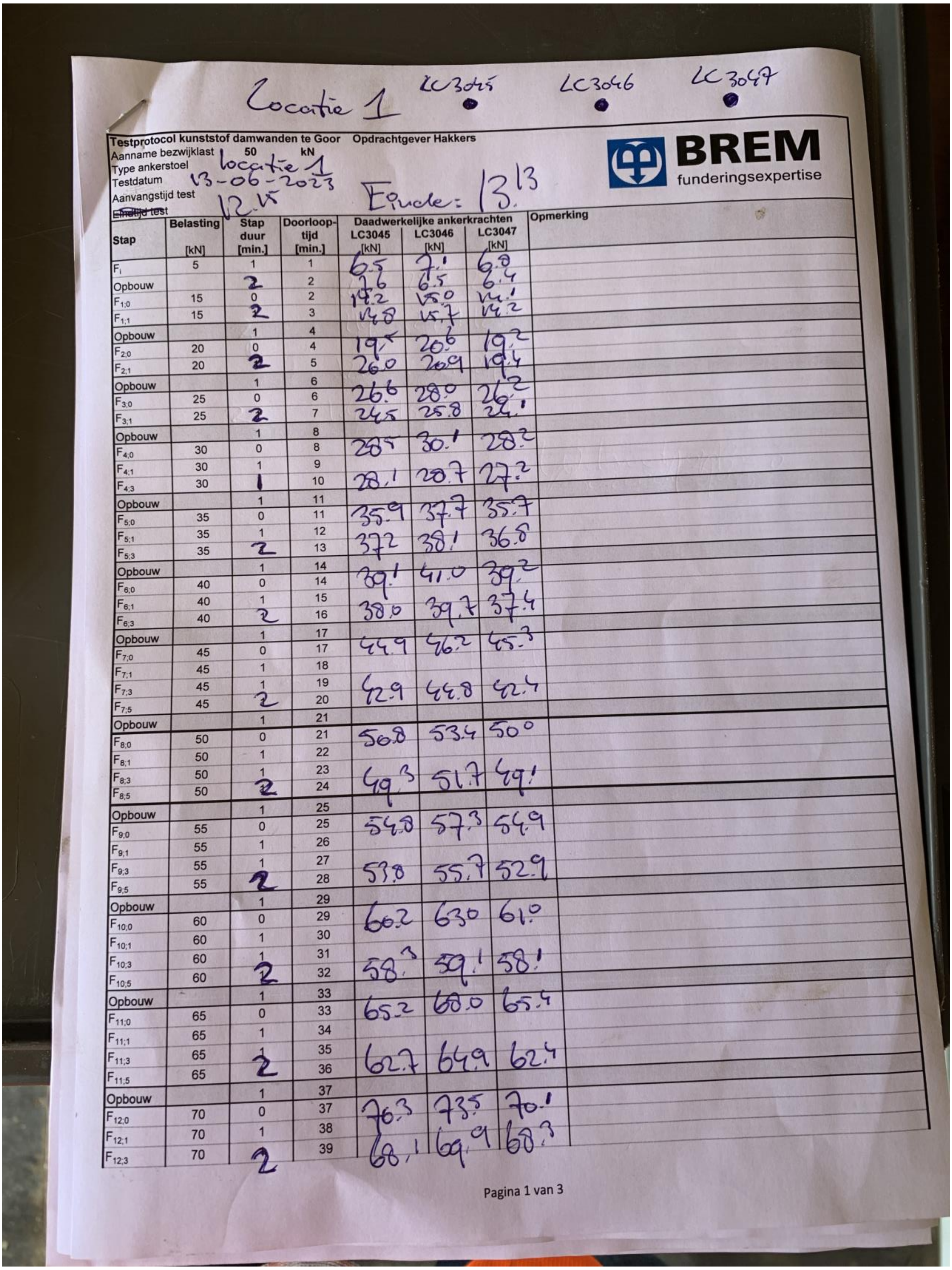
Samenvatting ankerontwerp

Zelfborend	:	Ø 42,4x11,0
L_{totaal} (ankerlengte praktisch)	:	14,00 m
L_{grout}	:	5,64 m
L_{over}	:	0,50 m
Boorkop diameter	:	180 mm
Ankerhoek tov hor.	:	45 °
Ankerhoek tov vert. (offset)	:	0 °
H.o.h. afstand	:	2,75 m^1
Trajectlengte	:	0,00 m^1
Aantal ankers	:	0 st

Testbelastingen

$P_P = \gamma_{a;sui,ULS} \times E_{ULS,d}$	=	440 kN
**Als BGT maatgevend is wordt getoetst op $E_{ULS,k}$/1,35*		
P_i (initiële kracht)	=	45 kN
40% P_{test}	=	175 kN
55% P_{test}	=	240 kN
70% P_{test}	=	310 kN
85% P_{test}	=	375 kN
100% P_{test}	=	440 kN
P_{vsp} voorspanning	=	100 kN
Max. $R_{t;d}$ (staal)	=	465 kN
(vóór corrosie en uitgaande van γ=1,1)		

11.5 Appendix E – Measurements BREM hydraulic jacks



Locatie 1 LC3045 LC3046 LC3047

Testprotocol kunststof damwanden te Goor **Opdrachtgever Hakkers**

BREM funderingsexpertise

Aanname bezwijklast 50 kN

Type ankerstoel locatie 1

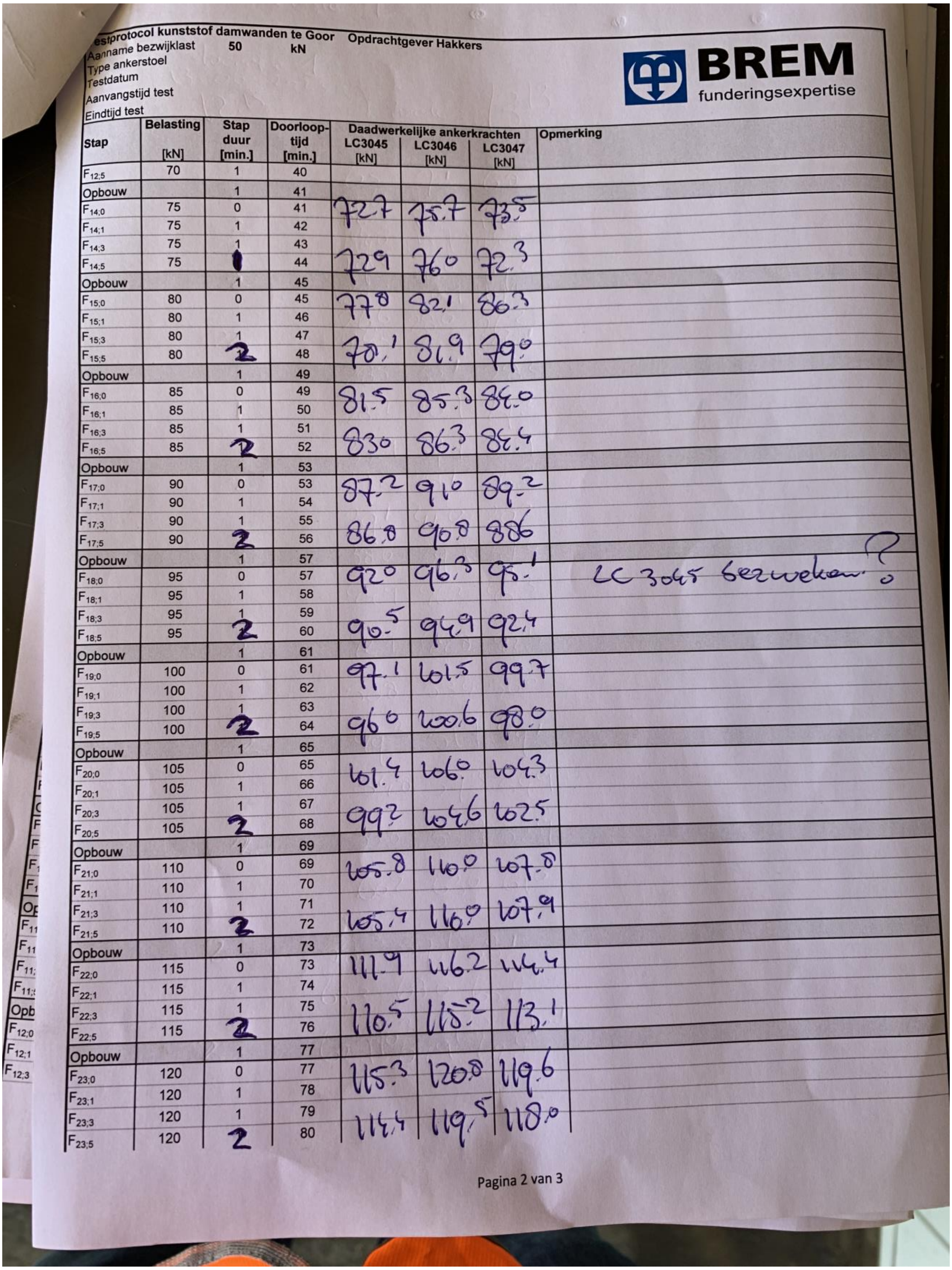
Testdatum 13-06-2023

Aanvangstijd test 12.15

~~Eindtijd test~~ Einde: 13.13

Stap	Belasting [kN]	Stap duur [min.]	Doorlooptijd [min.]	Daadwerkelijke ankerkrachten LC3045 [kN]	LC3046 [kN]	LC3047 [kN]	Opmerking
F_i	5	1	1	6.5	7.1	6.8	
Opbouw		2	2	7.6	6.5	6.4	
$F_{1;0}$	15	0	2	14.2	15.0	14.1	
$F_{1;1}$	15	2	3	14.8	15.7	14.2	
Opbouw		1	4				
$F_{2;0}$	20	0	4	19.5	20.6	19.2	
$F_{2;1}$	20	2	5	26.0	20.9	19.4	
Opbouw		1	6				
$F_{3;0}$	25	0	6	26.6	28.0	26.2	
$F_{3;1}$	25	2	7	24.5	25.8	24.1	
Opbouw		1	8				
$F_{4;0}$	30	0	8	28.5	30.1	28.2	
$F_{4;1}$	30	1	9				
$F_{4;3}$	30	1	10	28.1	28.7	27.2	
Opbouw		1	11				
$F_{5;0}$	35	0	11	35.9	37.7	35.7	
$F_{5;1}$	35	1	12				
$F_{5;3}$	35	2	13	37.2	38.1	36.8	
Opbouw		1	14				
$F_{6;0}$	40	0	14	39.1	41.0	39.2	
$F_{6;1}$	40	1	15				
$F_{6;3}$	40	2	16	38.0	39.7	37.4	
Opbouw		1	17				
$F_{7;0}$	45	0	17	44.9	46.2	45.3	
$F_{7;1}$	45	1	18				
$F_{7;3}$	45	1	19	42.9	44.8	42.4	
$F_{7;5}$	45	2	20				
Opbouw		1	21				
$F_{8;0}$	50	0	21	50.8	53.4	50.0	
$F_{8;1}$	50	1	22				
$F_{8;3}$	50	1	23	49.3	51.7	49.1	
$F_{8;5}$	50	2	24				
Opbouw		1	25				
$F_{9;0}$	55	0	25	54.8	57.3	54.9	
$F_{9;1}$	55	1	26				
$F_{9;3}$	55	1	27	53.8	55.7	52.9	
$F_{9;5}$	55	2	28				
Opbouw		1	29				
$F_{10;0}$	60	0	29	60.2	63.0	61.0	
$F_{10;1}$	60	1	30				
$F_{10;3}$	60	1	31	58.3	59.1	58.1	
$F_{10;5}$	60	2	32				
Opbouw		1	33				
$F_{11;0}$	65	0	33	65.2	68.0	65.4	
$F_{11;1}$	65	1	34				
$F_{11;3}$	65	1	35	62.7	64.9	62.4	
$F_{11;5}$	65	2	36				
Opbouw		1	37				
$F_{12;0}$	70	0	37	70.3	73.5	70.1	
$F_{12;1}$	70	1	38	68.1	69.9	68.3	
$F_{12;3}$	70	2	39				

Pagina 1 van 3



estprotocol kunststof damwanden te Goor — Opdrachtgever Hakkers

BREM funderingsexpertise

Aanname bezwijklast 50 kN
Type ankerstoel
Testdatum
Aanvangstijd test
Eindtijd test

Stap	Belasting [kN]	Stap duur [min.]	Doorloop-tijd [min.]	Daadwerkelijke ankerkrachten LC3045 [kN]	LC3046 [kN]	LC3047 [kN]	Opmerking
$F_{12;5}$	70	1	40				
Opbouw		1	41				
$F_{14;0}$	75	0	41	72.7	75.7	73.5	
$F_{14;1}$	75	1	42				
$F_{14;3}$	75	1	43				
$F_{14;5}$	75	1	44	72.9	76.0	72.3	
Opbouw		1	45				
$F_{15;0}$	80	0	45	77.8	82.1	86.3	
$F_{15;1}$	80	1	46				
$F_{15;3}$	80	1	47				
$F_{15;5}$	80	2	48	70.1	81.9	79.0	
Opbouw		1	49				
$F_{16;0}$	85	0	49	81.5	85.3	84.0	
$F_{16;1}$	85	1	50				
$F_{16;3}$	85	1	51				
$F_{16;5}$	85	2	52	83.0	86.3	84.4	
Opbouw		1	53				
$F_{17;0}$	90	0	53	87.2	91.0	89.2	
$F_{17;1}$	90	1	54				
$F_{17;3}$	90	1	55				
$F_{17;5}$	90	2	56	86.8	90.8	88.6	
Opbouw		1	57				
$F_{18;0}$	95	0	57	92.0	96.3	95.1	LC 3045 bezweken?
$F_{18;1}$	95	1	58				
$F_{18;3}$	95	1	59				
$F_{18;5}$	95	2	60	90.5	94.9	92.4	
Opbouw		1	61				
$F_{19;0}$	100	0	61	97.1	101.5	99.7	
$F_{19;1}$	100	1	62				
$F_{19;3}$	100	1	63				
$F_{19;5}$	100	2	64	96.0	100.6	98.0	
Opbouw		1	65				
$F_{20;0}$	105	0	65	101.4	106.0	104.3	
$F_{20;1}$	105	1	66				
$F_{20;3}$	105	1	67				
$F_{20;5}$	105	2	68	99.2	104.6	102.5	
Opbouw		1	69				
$F_{21;0}$	110	0	69	105.8	110.0	107.8	
$F_{21;1}$	110	1	70				
$F_{21;3}$	110	1	71				
$F_{21;5}$	110	2	72	105.4	110.0	107.9	
Opbouw		1	73				
$F_{22;0}$	115	0	73	111.9	116.2	114.4	
$F_{22;1}$	115	1	74				
$F_{22;3}$	115	1	75				
$F_{22;5}$	115	2	76	110.5	115.2	113.1	
Opbouw		1	77				
$F_{23;0}$	120	0	77	115.3	120.8	119.6	
$F_{23;1}$	120	1	78				
$F_{23;3}$	120	1	79				
$F_{23;5}$	120	2	80	114.4	119.5	118.0	

Pagina 2 van 3

...stprotocol kunststof damwanden te Goor — Opdrachtgever Hakkers

BREM funderingsexpertise

...anname bezwijklast 50 kN
Type ankerstoel
Testdatum
Aanvangstijd test
Eindtijd test

Stap	Belasting [kN]	Stap duur [min.]	Doorloop-tijd [min.]	Daadwerkelijke ankerkrachten LC3045 [kN]	LC3046 [kN]	LC3047 [kN]	Opmerking
Opbouw		1	81				
$F_{24;0}$	125	0	81	122.2	125.8	125.5	
$F_{24;1}$	125	1	82				
$F_{24;3}$	125	1	83				
$F_{24;5}$	125	1 (2)	84	119.2	124.9	123.4	
Opbouw		1	85				
$F_{25;0}$	130	0	85	126.6	130.9	129.8	
$F_{25;1}$	130	1	86				
$F_{25;3}$	130	1	87				
$F_{25;5}$	130	1 (2)	88	124.4	130.0	128.7	
Opbouw		1	89				
$F_{26;0}$	135	0	89				Wil niet op 135.0
$F_{26;1}$	135	1	90				Bezweken om 13.13
$F_{26;3}$	135	1	91				
$F_{27;5}$	135	1	92				
Opbouw		1	93				
$F_{28;0}$	140	0	93				
$F_{28;1}$	140	1	94				
$F_{28;3}$	140	1	95				
$F_{28;5}$	140	1	96				
Opbouw		1	97				
$F_{29;0}$	140	0	97				
$F_{29;1}$	140	1	98				
$F_{29;3}$	140	1	99				
$F_{29;5}$	140	1	100				
Opbouw		1	101				
$F30_{;0}$	140	0	101				
$F30_{;1}$	140	1	102				
$F30_{;3}$	140	1	103				
$F30_{;5}$	140	1	104				
Einde		1	105				

Locatie 2 LC3045 LC3047 LC3046

Testprotocol kunststof damwanden te Goor Opdrachtgever Hakkers

BREM funderingsexpertise

Aanname bezwijklast 50 kN
Type ankerstoel Locatie 2
Testdatum 13-6-2023
Aanvangstijd test 10.45
~~Eindtijd test~~ Einde: 11.44

Stap	Belasting [kN]	Stap duur [min.]	Doorloop-tijd [min.]	Daadwerkelijke ankerkrachten LC3045 [kN]	LC3046 [kN]	LC3047 [kN]	Opmerking
F_i	5	1	1	5.8	6.5	5.1	
Opbouw		3	2	7.0	7.3	6.7	
$F_{1;0}$	15	0	2	15.2	16.0	15.2	
$F_{1;1}$	15	4	3	16.9	15.7	16.0	
Opbouw		1	4				
$F_{2;0}$	20	0	4	18.7	19.5	18.9	
$F_{2;1}$	20	2	5	20.0	21.1	20.1	
Opbouw		1	6				
$F_{3;0}$	25	0	6	26.9	27.2	26.0	
$F_{3;1}$	25	3	7	24.5	26.3	24.7	
Opbouw		1	8				
$F_{4;0}$	30	0	8	31.0	31.4	30.0	
$F_{4;1}$	30	1	9				
$F_{4;3}$	30	2	10	28.6	36.6	28.8	
Opbouw		1	11				
$F_{5;0}$	35	0	11	35.6	35.9	34.6	
$F_{5;1}$	35	1	12				
$F_{5;3}$	35	2	13	33.3	34.9	33.4	
Opbouw		1	14				
$F_{6;0}$	40	0	14	40.5	41.2	40.0	
$F_{6;1}$	40	1	15				
$F_{6;3}$	40	2	16	38.3	39.9	38.4	
Opbouw		1	17				
$F_{7;0}$	45	0	17	45.6	46.0	46.1	
$F_{7;1}$	45	1	18				
$F_{7;3}$	45	1	19				
$F_{7;5}$	45	2	20	42.9	45.6	43.2	
Opbouw		1	21				
$F_{8;0}$	50	0	21	50.4	52.1	49.6	
$F_{8;1}$	50	1	22				
$F_{8;3}$	50	1	23				
$F_{8;5}$	50	2	24	47.2	49.5	48.1	
Opbouw		1	25				
$F_{9;0}$	55	0	25	56.4	58.1	55.4	
$F_{9;1}$	55	1	26				
$F_{9;3}$	55	2	28	56.0	58.7	55.9	
$F_{9;5}$	55	2	28	54.8	57.6	55.1	
Opbouw		1	30				
$F_{10;0}$	60	0	30	60.8	62.9	59.5	
$F_{10;1}$	60	1	31				
$F_{10;3}$	60	2	33	57.2	59.1	58.1	
$F_{10;5}$	60	2	35	59.4	61.7	58.9	
Opbouw		1	35				
$F_{11;0}$	65	0	35	65.9	67.4	66.3	
$F_{11;1}$	65	1	36				
$F_{11;3}$	65	2	38	65.0	67.1	66.2	
$F_{11;5}$	65	2	[illegible]				
Opbouw		1	[illegible]				
$F_{12;0}$	70	0	[illegible]	69.3	72.8	68.4	
$F_{12;1}$	70	1	48				
$F_{12;3}$	70	1½	[illegible]	67.2	69.7	66.8	

2.0.2

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Aanname bezwijklast 50 kN

Type ankerstoel

Testdatum

Aanvangstijd test

Eindtijd test

BREM funderingsexpertise

Stap	Belasting [kN]	Stap duur [min.]	Doorloop-tijd [min.]	Daadwerkelijke ankerkrachten LC3045 [kN]	LC3046 [kN]	LC3047 [kN]	Opmerking
$F_{12;5}$	70	2	40				
Opbouw		1	41				
$F_{14;0}$	75	0	41	74.4	77.2	73.1	
$F_{14;1}$	75	1	42				
$F_{14;3}$	75	1	43				
$F_{14;5}$	75	3	43	74.0	76.3	74.2	
Opbouw		1	45				
$F_{15;0}$	80	0	45	78.4	80.8	77.7	
$F_{15;1}$	80	1	46				
$F_{15;3}$	80	1	47				
$F_{15;5}$	80	2	48	78.0	80.6	77.6	
Opbouw		1	49				
$F_{16;0}$	85	0	49	85.3	86.4	84.7	
$F_{16;1}$	85	1	50				
$F_{16;3}$	85	1	51				
$F_{16;5}$	85	2	52	84.0	85.2	83.1	
Opbouw		1	53				
$F_{17;0}$	90	0	53				Wilwet op 90°
$F_{17;1}$	90	1	54				Damwand kracht
$F_{17;3}$	90	1	55				Bezweken om 11.44
$F_{17;5}$	90	1	56				
Opbouw		1	57				
$F_{18;0}$	95	0	57				
$F_{18;1}$	95	1	58				
$F_{18;3}$	95	1	59				
$F_{18;5}$	95	1	60				
Opbouw		1	61				
$F_{19;0}$	100	0	61				
$F_{19;1}$	100	1	62				
$F_{19;3}$	100	1	63				
$F_{19;5}$	100	1	64				
Opbouw		1	65				
$F_{20;0}$	105	0	65				
$F_{20;1}$	105	1	66				
$F_{20;3}$	105	1	67				
$F_{20;5}$	105	1	68				
Opbouw		1	69				
$F_{21;0}$	110	0	69				
$F_{21;1}$	110	1	70				
$F_{21;3}$	110	1	71				
$F_{21;5}$	110	1	72				
Opbouw		1	73				
$F_{22;0}$	115	0	73				
$F_{22;1}$	115	1	74				
$F_{22;3}$	115	1	75				
$F_{22;5}$	115	1	76				
Opbouw		1	77				
$F_{23;0}$	120	0	77				
$F_{23;1}$	120	1	78				
$F_{23;3}$	120	1	79				
$F_{23;5}$	120	1	80				

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Locatie 3

Testprotocol kunststof damwanden te Goor **Opdrachtgever Hakkers**

BREM funderingsexpertise

Aanname bezwijklast 50 kN
Type ankerstoel
Testdatum 12-06-2023
Aanvangstijd test 10.38
~~Eindtijd test~~ Einde: 11.12

Stap	Belasting [kN]	Stap duur [min.]	Doorloop-tijd [min.]	Daadwerkelijke ankerkrachten LC3045 [kN]	LC3046 [kN]	LC3047 [kN]	Opmerking
F_i	5	1	1	6.9	6.7	6.5	
Opbouw	15	0	2	15.2	16.1	15.9	
$F_{1;0}$	15	1	2	14.0	14.7	14.2	
$F_{1;1}$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Opbouw		1	4				
$F_{2;0}$	20	0	4	20.0	20.8	20.0	
$F_{2;1}$	20	3	5	17.5	17.9	17.6	
Opbouw		1	6				
$F_{3;0}$	25	0	6	25.1	25.9	25.7	
$F_{3;1}$	25	3	7	24.6	25.6	24.9	
Opbouw		1	8				
$F_{4;0}$	30	0	8	30.2	30.9	30.2	Bij 3045+3046 begint
$F_{4;1}$	30	1	9				damwand te scheuren.
$F_{4;3}$	30	5	10	29.1	30.2	29.6	
Opbouw		1	11				
$F_{5;0}$	35	0	11	34.6	36.0	35.1	
$F_{5;1}$	35	1	12				
$F_{5;3}$	35	6	13	33.9	35.5	34.5	
Opbouw		1	14				
$F_{6;0}$	40	0	14	39.4	40.2	39.7	
$F_{6;1}$	40	1	15				
$F_{6;3}$	40	4	16	38.5	40	39.2	
Opbouw		1	17				
$F_{7;0}$	45	0	17	44.7	45.2	45.5	
$F_{7;1}$	45	1	18				
$F_{7;3}$	45	1	19				
$F_{7;5}$	45	3	20	42.1	43.9	43.3	
Opbouw		1	21				
$F_{8;0}$	50	0	21				Wil niet hoger dan 42.0
$F_{8;1}$	50	1	22				Damwand gescheurd
$F_{8;3}$	50	1	23				Beëindigen 11.12 uur
$F_{8;5}$	50	1	24				
Opbouw		1	25				
$F_{9;0}$	55	0	25				
$F_{9;1}$	55	1	26				
$F_{9;3}$	55	1	27				
$F_{9;5}$	55	1	28				
Opbouw		1	29				
$F_{10;0}$	60	0	29				
$F_{10;1}$	60	1	30				
$F_{10;3}$	60	1	31				
$F_{10;5}$	60	1	32				
Opbouw		1	33				
$F_{11;0}$	65	0	33				
$F_{11;1}$	65	1	34				
$F_{11;3}$	65	1	35				
$F_{11;5}$	65	1	36				
Opbouw		1	37				
$F_{12;0}$	70	0	37				
$F_{12;1}$	70	1	38				
$F_{12;3}$	70	1	39				

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11.6 Appendix F – Measured displacements

Location 1

NULMETING	x [mm]	y [mm]	z [mm]	Time and date
1_begin	55111	10456	895	13-6-2023 12:11
2_begin	55112	10486	3175	13-6-2023 12:12
3_begin	57821	10416	856	13-6-2023 12:12
4_begin	57834	10467	3172	13-6-2023 12:12
5_begin	60561	10406	853	13-6-2023 12:12
6_begin	60561	10446	3173	13-6-2023 12:12
11_begin	68779	10477	894	13-6-2023 12:13
12_begin	68786	10500	3185	13-6-2023 12:14
13_begin	71516	10468	936	13-6-2023 12:14
14_begin	71531	10499	3171	13-6-2023 12:14
15_begin	74252	10483	846	13-6-2023 12:14
16_begin	74253	10494	3177	13-6-2023 12:14
21_begin	79754	10489	853	13-6-2023 12:15
22_begin	79752	10485	3204	13-6-2023 12:15
23_begin	82490	10465	900	13-6-2023 12:15
24_begin	82493	10503	3192	13-6-2023 12:15
25_begin	85228	10473	888	13-6-2023 12:16
26_begin	85232	10514	3177	13-6-2023 12:16
Pressure [kN]	**x [mm]**	**y [mm]**	**z [mm]**	**Time and date**
21_5KN	79754	10489	852	13-6-2023 12:17
22_5KN	79752	10483	3204	13-6-2023 12:17
23_5KN	82490	10465	900	13-6-2023 12:17
24_5KN	82493	10501	3193	13-6-2023 12:18
25_5KN	85228	10472	888	13-6-2023 12:18
26_5KN	85232	10512	3177	13-6-2023 12:18
21_15KN	79754	10489	853	13-6-2023 12:19
22_15KN	79752	10481	3204	13-6-2023 12:19
23_15KN	82491	10465	900	13-6-2023 12:20
24_15KN	82493	10497	3193	13-6-2023 12:20
25_15KN	85228	10472	888	13-6-2023 12:20
26_15KN	85232	10507	3177	13-6-2023 12:20
21_20KN	79754	10489	853	13-6-2023 12:21
22_20KN	79752	10479	3205	13-6-2023 12:22
23_20KN	82491	10465	900	13-6-2023 12:22
24_20KN	82494	10495	3193	13-6-2023 12:22
25_20KN	85228	10472	888	13-6-2023 12:22
26_20KN	85232	10505	3177	13-6-2023 12:22

21_25KN	79754	10489	853	13-6-2023 12:24
22_25KN	79752	10477	3205	13-6-2023 12:24
23_25KN	82490	10465	900	13-6-2023 12:24
24_25KN	82494	10494	3193	13-6-2023 12:25
25_25KN	85228	10472	888	13-6-2023 12:25
26_25KN	85232	10504	3177	13-6-2023 12:25
15_25KN	74254	10482	846	13-6-2023 12:25
16_25KN	74253	10494	3177	13-6-2023 12:26
21_30KN	79754	10489	853	13-6-2023 12:26
22_30KN	79752	10476	3205	13-6-2023 12:26
23_30KN	82491	10465	900	13-6-2023 12:27
24_30KN	82494	10493	3193	13-6-2023 12:27
25_30KN	85228	10472	888	13-6-2023 12:27
26_30KN	85232	10503	3177	13-6-2023 12:27
21_35KN	79754	10489	853	13-6-2023 12:29
22_35KN	79752	10475	3205	13-6-2023 12:29
23_35KN	82490	10464	900	13-6-2023 12:29
24_35KN	82494	10492	3193	13-6-2023 12:29
25_35KN	85228	10472	888	13-6-2023 12:29
26_35KN	85231	10502	3177	13-6-2023 12:29
21_40KN	79754	10489	853	13-6-2023 12:30
22_40KN	79752	10474	3205	13-6-2023 12:30
23_40KN	82491	10464	900	13-6-2023 12:30
24_40KN	82494	10491	3193	13-6-2023 12:31
25_40KN	85228	10472	888	13-6-2023 12:31
26_40KN	85231	10500	3178	13-6-2023 12:31
21_45KN	79754	10489	853	13-6-2023 12:32
22_45KN	79752	10473	3205	13-6-2023 12:32
23_45KN	82490	10465	900	13-6-2023 12:32
24_45KN	82494	10490	3193	13-6-2023 12:32
25_45KN	85228	10472	888	13-6-2023 12:33
26_45KN	85231	10499	3177	13-6-2023 12:33
21_50KN	79754	10488	853	13-6-2023 12:34
22_50KN	79752	10471	3205	13-6-2023 12:34
23_50KN	82491	10464	900	13-6-2023 12:34
24_50KN	82494	10488	3193	13-6-2023 12:35
25_50KN	85228	10472	888	13-6-2023 12:35
26_50KN	85232	10497	3177	13-6-2023 12:35
21_55KN	79754	10488	853	13-6-2023 12:37
22_55KN	79752	10469	3205	13-6-2023 12:37
23_55KN	82490	10464	900	13-6-2023 12:37
24_55KN	82494	10487	3193	13-6-2023 12:37
25_55KN	85228	10472	888	13-6-2023 12:37
26_55KN	85231	10495	3178	13-6-2023 12:37

21_60KN	79754	10489	852	13-6-2023 12:39
22_60KN	79753	10468	3205	13-6-2023 12:39
23_60KN	82490	10464	900	13-6-2023 12:39
24_60KN	82494	10486	3193	13-6-2023 12:39
25_60KN	85228	10472	888	13-6-2023 12:39
26_60KN	85231	10494	3178	13-6-2023 12:40
21_65KN	79754	10488	853	13-6-2023 12:40
22_65KN	79752	10467	3205	13-6-2023 12:40
23_65KN	82491	10464	900	13-6-2023 12:41
24_65KN	82495	10484	3193	13-6-2023 12:41
25_65KN	85228	10472	888	13-6-2023 12:41
26_65KN	85231	10492	3178	13-6-2023 12:41
21_70KN	79754	10488	853	13-6-2023 12:42
22_70KN	79752	10465	3205	13-6-2023 12:42
23_70KN	82491	10464	900	13-6-2023 12:42
24_70KN	82495	10483	3193	13-6-2023 12:42
25_70KN	85228	10472	888	13-6-2023 12:43
26_70KN	85231	10491	3178	13-6-2023 12:43
21_75KN	79754	10488	853	13-6-2023 12:44
22_75KN	79753	10465	3205	13-6-2023 12:44
23_75KN	82491	10464	900	13-6-2023 12:45
24_75KN	82495	10482	3193	13-6-2023 12:45
25_75KN	85228	10472	888	13-6-2023 12:45
26_75KN	85231	10490	3178	13-6-2023 12:45
21_80KN	79754	10488	853	13-6-2023 12:47
22_80KN	79753	10463	3205	13-6-2023 12:47
23_80KN	82490	10464	900	13-6-2023 12:47
24_80KN	82495	10481	3193	13-6-2023 12:47
25_80KN	85228	10472	888	13-6-2023 12:47
26_80KN	85231	10487	3178	13-6-2023 12:48
21_85KN	79754	10488	853	13-6-2023 12:49
22_85KN	79753	10462	3205	13-6-2023 12:49
23_85KN	82490	10464	899	13-6-2023 12:49
24_85KN	82495	10480	3193	13-6-2023 12:49
25_85KN	85228	10472	888	13-6-2023 12:50
26_85KN	85231	10485	3178	13-6-2023 12:50
21_90KN	79754	10489	853	13-6-2023 12:51
22_90KN	79753	10461	3205	13-6-2023 12:52
23_90KN	82491	10464	900	13-6-2023 12:52
24_90KN	82496	10479	3193	13-6-2023 12:52
25_90KN	85228	10472	888	13-6-2023 12:52
26_90KN	85230	10484	3178	13-6-2023 12:52
21_95KN	79754	10488	853	13-6-2023 12:54
22_95KN	79753	10460	3205	13-6-2023 12:54

23_95KN	82491	10464	900	13-6-2023 12:54
24_95KN	82495	10478	3193	13-6-2023 12:54
25_95KN	85228	10472	888	13-6-2023 12:55
26_95KN	85229	10480	3178	13-6-2023 12:55
21_100KN	79754	10489	853	13-6-2023 12:56
22_100KN	79753	10458	3205	13-6-2023 12:56
23_100KN	82490	10464	900	13-6-2023 12:56
24_100KN	82496	10477	3193	13-6-2023 12:57
25_100KN	85228	10472	888	13-6-2023 12:57
26_100KN	85228	10477	3178	13-6-2023 12:57
21_105KN	79753	10488	852	13-6-2023 12:59
22_105KN	79753	10457	3205	13-6-2023 12:59
23_105KN	82490	10464	900	13-6-2023 12:59
24_105KN	82496	10476	3193	13-6-2023 12:59
25_105KN	85228	10472	888	13-6-2023 12:59
26_105KN	85227	10475	3178	13-6-2023 13:00
21_110KN	79754	10488	853	13-6-2023 13:01
22_110KN	79753	10456	3205	13-6-2023 13:01
23_110KN	82490	10464	900	13-6-2023 13:01
24_110KN	82497	10475	3193	13-6-2023 13:02
25_110KN	85228	10472	888	13-6-2023 13:02
26_110KN	85227	10472	3178	13-6-2023 13:02
21_115KN	79754	10488	853	13-6-2023 13:03
22_115KN	79753	10455	3205	13-6-2023 13:04
23_115KN	82490	10464	900	13-6-2023 13:04
24_115KN	82497	10475	3193	13-6-2023 13:04
25_115KN	85228	10472	888	13-6-2023 13:04
26_115KN	85227	10471	3178	13-6-2023 13:05
21_120KN	79754	10488	853	13-6-2023 13:06
22_120KN	79754	10455	3205	13-6-2023 13:06
23_120KN	82490	10465	900	13-6-2023 13:06
24_120KN	82498	10476	3193	13-6-2023 13:07
25_120KN	85228	10472	888	13-6-2023 13:07
26_120KN	85225	10466	3179	13-6-2023 13:07
21_125KN	79754	10488	853	13-6-2023 13:09
22_125KN	79754	10453	3205	13-6-2023 13:09
23_125KN	82490	10464	900	13-6-2023 13:09
24_125KN	82497	10479	3193	13-6-2023 13:09
25_125KN	85229	10472	888	13-6-2023 13:10
26_125KN	85224	10461	3178	13-6-2023 13:10
21_130KN	79754	10488	852	13-6-2023 13:11
22_130KN	79755	10452	3205	13-6-2023 13:12
23_130KN	82490	10464	900	13-6-2023 13:12
24_130KN	82496	10481	3192	13-6-2023 13:12

25_130KN	85228	10472	888	13-6-2023 13:12
26_130KN	85224	10459	3179	13-6-2023 13:12
GEEN DRUK				
1_eind	55111	10456	894	13-6-2023 13:16
2_eind	55112	10485	3176	13-6-2023 13:16
3_eind	57822	10416	856	13-6-2023 13:17
4_eind	57835	10466	3172	13-6-2023 13:17
5_eind	60561	10406	852	13-6-2023 13:17
6_eind	60562	10446	3173	13-6-2023 13:17
11_eind	68779	10476	894	13-6-2023 13:17
12_eind	68787	10500	3185	13-6-2023 13:18
13_eind	71516	10467	936	13-6-2023 13:18
14_eind	71531	10498	3171	13-6-2023 13:18
15_eind	74254	10483	845	13-6-2023 13:18
16_eind	74253	10494	3177	13-6-2023 13:18
21_eind	79754	10489	853	13-6-2023 13:19
22_eind	79756	10485	3205	13-6-2023 13:19
23_eind	82490	10465	900	13-6-2023 13:19
24_eind	82497	10505	3193	13-6-2023 13:20
25_eind	85228	10473	888	13-6-2023 13:20
26_eind	85230	10511	3177	13-6-2023 13:20

Location 2

NULMETING	x [mm]	y [mm]	z [mm]	Time and date
1	55111	10457	896	13-6-2023 08:52
2	55112	10487	3175	13-6-2023 08:52
3	57821	10418	856	13-6-2023 08:52
4	57835	10468	3173	13-6-2023 08:52
5	60560	10406	853	13-6-2023 08:53
6	60561	10447	3173	13-6-2023 08:53
11	68778	10478	895	13-6-2023 08:53
12	68784	10503	3185	13-6-2023 08:54
13	71515	10468	936	13-6-2023 08:54
14	71530	10501	3171	13-6-2023 08:54
15	74254	10484	846	13-6-2023 08:54
16	74253	10494	3178	13-6-2023 08:54
21	79754	10490	853	13-6-2023 08:55
22	79752	10474	3205	13-6-2023 08:55
23	82490	10466	901	13-6-2023 08:55
24	82493	10491	3193	13-6-2023 08:55
25	85228	10474	889	13-6-2023 08:56
26	85232	10511	3177	13-6-2023 08:56
1	55111	10456	896	13-6-2023 09:23
2	55112	10487	3176	13-6-2023 09:24
3	57821	10418	857	13-6-2023 09:24
4	57834	10468	3173	13-6-2023 09:24
5	60561	10406	852	13-6-2023 09:24
6	60561	10446	3173	13-6-2023 09:25
11	68779	10477	894	13-6-2023 09:25
12	68785	10502	3185	13-6-2023 09:25
13	71516	10468	936	13-6-2023 09:25
14	71530	10501	3172	13-6-2023 09:26
15	74254	10484	847	13-6-2023 09:26
16	74253	10494	3178	13-6-2023 09:26
21	79754	10490	853	13-6-2023 09:26
22	79752	10473	3205	13-6-2023 09:26
23	82491	10465	901	13-6-2023 09:27
24	82494	10490	3193	13-6-2023 09:27
25	85228	10474	889	13-6-2023 09:27
26	85232	10511	3178	13-6-2023 09:27
1	55111	10456	895	13-6-2023 09:49

2	55111	10486	3176	13-6-2023 09:49
3	57821	10417	857	13-6-2023 09:49
4	57834	10467	3173	13-6-2023 09:49
5	60560	10406	853	13-6-2023 09:50
6	60561	10446	3174	13-6-2023 09:50
11	68779	10477	895	13-6-2023 09:50
12	68785	10502	3186	13-6-2023 09:50
13	71515	10467	936	13-6-2023 09:50
14	71530	10500	3172	13-6-2023 09:51
15	74254	10483	847	13-6-2023 09:51
16	74253	10494	3178	13-6-2023 09:51
21	79754	10489	853	13-6-2023 09:51
22	79752	10472	3205	13-6-2023 09:51
23	82490	10464	901	13-6-2023 09:51
24	82494	10490	3193	13-6-2023 09:52
25	85228	10473	889	13-6-2023 09:52
26	85232	10510	3178	13-6-2023 09:52
1_begin	55111	10456	896	13-6-2023 10:17
2_begin	55111	10486	3176	13-6-2023 10:18
3_begin	57821	10417	856	13-6-2023 10:18
4_begin	57835	10467	3172	13-6-2023 10:18
5_begin	60561	10406	852	13-6-2023 10:18
6_begin	60561	10446	3172	13-6-2023 10:18
11_begin	68779	10477	894	13-6-2023 10:19
12_begin	68785	10502	3185	13-6-2023 10:19
13_begin	71516	10468	935	13-6-2023 10:19
14_begin	71530	10500	3171	13-6-2023 10:19
15_begin	74254	10483	846	13-6-2023 10:20
16_begin	74253	10494	3178	13-6-2023 10:20
21_begin	79754	10489	853	13-6-2023 10:20
22_begin	79752	10472	3205	13-6-2023 10:20
23_begin	82490	10464	900	13-6-2023 10:20
24_begin	82494	10490	3193	13-6-2023 10:21
25_begin	85228	10473	888	13-6-2023 10:21
26_begin	85232	10510	3177	13-6-2023 10:21
Pressure [kN]	**x [mm]**	**y [mm]**	**z [mm]**	**Time and date**
11_5KN	68779	10476	893	13-6-2023 10:48
12_5KN	68785	10501	3185	13-6-2023 10:49
13_5KN	71517	10467	936	13-6-2023 10:49

14_5KN	71531	10499	3171	13-6-2023 10:49
15_5KN	74254	10483	846	13-6-2023 10:50
16_5KN	74253	10492	3178	13-6-2023 10:50
11_15KN	68779	10476	894	13-6-2023 10:51
12_15KN	68784	10498	3185	13-6-2023 10:52
13_15KN	71516	10467	935	13-6-2023 10:52
14_15KN	71530	10496	3171	13-6-2023 10:52
15_15KN	74254	10482	846	13-6-2023 10:53
16_15KN	74252	10491	3178	13-6-2023 10:53
11_20KN	68779	10476	894	13-6-2023 10:55
12_20KN	68784	10497	3185	13-6-2023 10:56
13_20KN	71516	10467	936	13-6-2023 10:56
14_20KN	71530	10496	3171	13-6-2023 10:56
15_20KN	74254	10482	846	13-6-2023 10:56
16_20KN	74252	10489	3178	13-6-2023 10:57
11_25KN	68779	10476	894	13-6-2023 10:58
12_25KN	68784	10496	3185	13-6-2023 10:58
13_25KN	71516	10467	935	13-6-2023 10:59
14_25KN	71530	10495	3171	13-6-2023 10:59
15_25KN	74254	10483	846	13-6-2023 10:59
16_25KN	74252	10489	3178	13-6-2023 11:00
11_30KN	68779	10477	894	13-6-2023 11:01
12_30KN	68784	10495	3185	13-6-2023 11:01
13_30KN	71516	10467	936	13-6-2023 11:01
14_30KN	71529	10493	3171	13-6-2023 11:02
15_30KN	74254	10483	845	13-6-2023 11:02
16_30KN	74252	10488	3178	13-6-2023 11:02
11_35KN	68779	10477	894	13-6-2023 11:03
12_35KN	68784	10494	3185	13-6-2023 11:03
13_35KN	71515	10467	936	13-6-2023 11:04
14_35KN	71530	10493	3171	13-6-2023 11:04
15_35KN	74254	10483	846	13-6-2023 11:04
16_35KN	74252	10487	3178	13-6-2023 11:05
11_40KN	68779	10477	894	13-6-2023 11:05
12_40KN	68784	10493	3185	13-6-2023 11:06
13_40KN	71516	10468	936	13-6-2023 11:06
14_40KN	71529	10491	3172	13-6-2023 11:06
15_40KN	74254	10482	846	13-6-2023 11:07
16_40KN	74252	10486	3178	13-6-2023 11:07
11_45KN	68779	10477	894	13-6-2023 11:08
12_45KN	68784	10492	3186	13-6-2023 11:08
13_45KN	71516	10467	936	13-6-2023 11:08
14_45KN	71529	10490	3172	13-6-2023 11:08
15_45KN	74254	10483	846	13-6-2023 11:09

16_45KN	74252	10485	3178	13-6-2023 11:09
11_50KN	68778	10477	894	13-6-2023 11:11
12_50KN	68783	10490	3185	13-6-2023 11:11
13_50KN	71516	10467	935	13-6-2023 11:11
14_50KN	71529	10489	3172	13-6-2023 11:12
15_50KN	74253	10483	846	13-6-2023 11:12
16_50KN	74251	10484	3178	13-6-2023 11:12
11_55KN	68779	10477	894	13-6-2023 11:13
12_55KN	68783	10489	3185	13-6-2023 11:13
13_55KN	71516	10467	936	13-6-2023 11:14
14_55KN	71529	10488	3172	13-6-2023 11:14
15_55KN	74254	10483	846	13-6-2023 11:14
16_55KN	74251	10483	3178	13-6-2023 11:14
11_60KN	68779	10477	894	13-6-2023 11:19
12_60KN	68783	10488	3185	13-6-2023 11:19
13_60KN	71516	10467	936	13-6-2023 11:19
14_60KN	71529	10486	3171	13-6-2023 11:20
15_60KN	74254	10483	846	13-6-2023 11:20
16_60KN	74251	10481	3178	13-6-2023 11:20
21_60KN	79754	10489	853	13-6-2023 11:21
22_60KN	79752	10472	3205	13-6-2023 11:21
23_60KN	82490	10464	900	13-6-2023 11:21
3_60KN	57821	10417	855	13-6-2023 11:22
4_60KN	57834	10468	3172	13-6-2023 11:23
5_60KN	60561	10406	852	13-6-2023 11:23
6_60KN	60562	10446	3172	13-6-2023 11:23
24_60KN	82494	10489	3193	13-6-2023 11:24
11_65KN	68779	10477	894	13-6-2023 11:25
12_65KN	68783	10487	3186	13-6-2023 11:26
13_65KN	71516	10467	935	13-6-2023 11:26
14_65KN	71529	10484	3172	13-6-2023 11:26
15_65KN	74254	10483	846	13-6-2023 11:26
16_65KN	74251	10480	3178	13-6-2023 11:27
11_70KN	68779	10477	894	13-6-2023 11:28
12_70KN	68783	10485	3185	13-6-2023 11:28
13_70KN	71516	10467	936	13-6-2023 11:28
14_70KN	71529	10483	3172	13-6-2023 11:29
15_70KN	74254	10483	846	13-6-2023 11:29
16_70KN	74251	10480	3178	13-6-2023 11:29
11_75KN	68779	10476	894	13-6-2023 11:30
12_75KN	68783	10483	3186	13-6-2023 11:31
13_75KN	71515	10467	936	13-6-2023 11:31
14_75KN	71529	10481	3172	13-6-2023 11:31
15_75KN	74254	10483	846	13-6-2023 11:31

16_75KN	74251	10479	3178	13-6-2023 11:32
11_80KN	68779	10476	894	13-6-2023 11:34
12_80KN	68783	10482	3186	13-6-2023 11:35
13_80KN	71516	10467	935	13-6-2023 11:35
14_80KN	71528	10480	3172	13-6-2023 11:35
15_80KN	74254	10483	846	13-6-2023 11:35
16_80KN	74250	10477	3178	13-6-2023 11:36
11_85KN	68779	10477	894	13-6-2023 11:37
12_85KN	68781	10480	3186	13-6-2023 11:37
13_85KN	71516	10467	935	13-6-2023 11:38
14_85KN	71528	10478	3172	13-6-2023 11:38
15_85KN	74254	10483	846	13-6-2023 11:38
16_85KN	74251	10476	3178	13-6-2023 11:38
ZONDER DRUK				
1_eind	55111	10456	895	13-6-2023 11:54
2_eind	55112	10486	3175	13-6-2023 11:54
3_eind	57821	10417	855	13-6-2023 11:54
4_eind	57835	10468	3172	13-6-2023 11:54
5_eind	60561	10406	852	13-6-2023 11:54
6_eind	60561	10446	3172	13-6-2023 11:54
11_eind	68779	10477	894	13-6-2023 11:55
13_eind	71516	10467	935	13-6-2023 11:55
14_eind	71531	10499	3171	13-6-2023 11:55
15_eind	74254	10483	846	13-6-2023 11:55
16_eind	74253	10493	3177	13-6-2023 11:55
21_eind	79754	10488	853	13-6-2023 11:56
22_eind	79752	10472	3205	13-6-2023 11:56
23_eind	82490	10464	900	13-6-2023 11:56
24_eind	82494	10489	3193	13-6-2023 11:56
25_eind	85228	10472	888	13-6-2023 11:56
26_eind	85232	10510	3177	13-6-2023 11:56
12_eind	68787	10500	3185	13-6-2023 12:02

Location 3

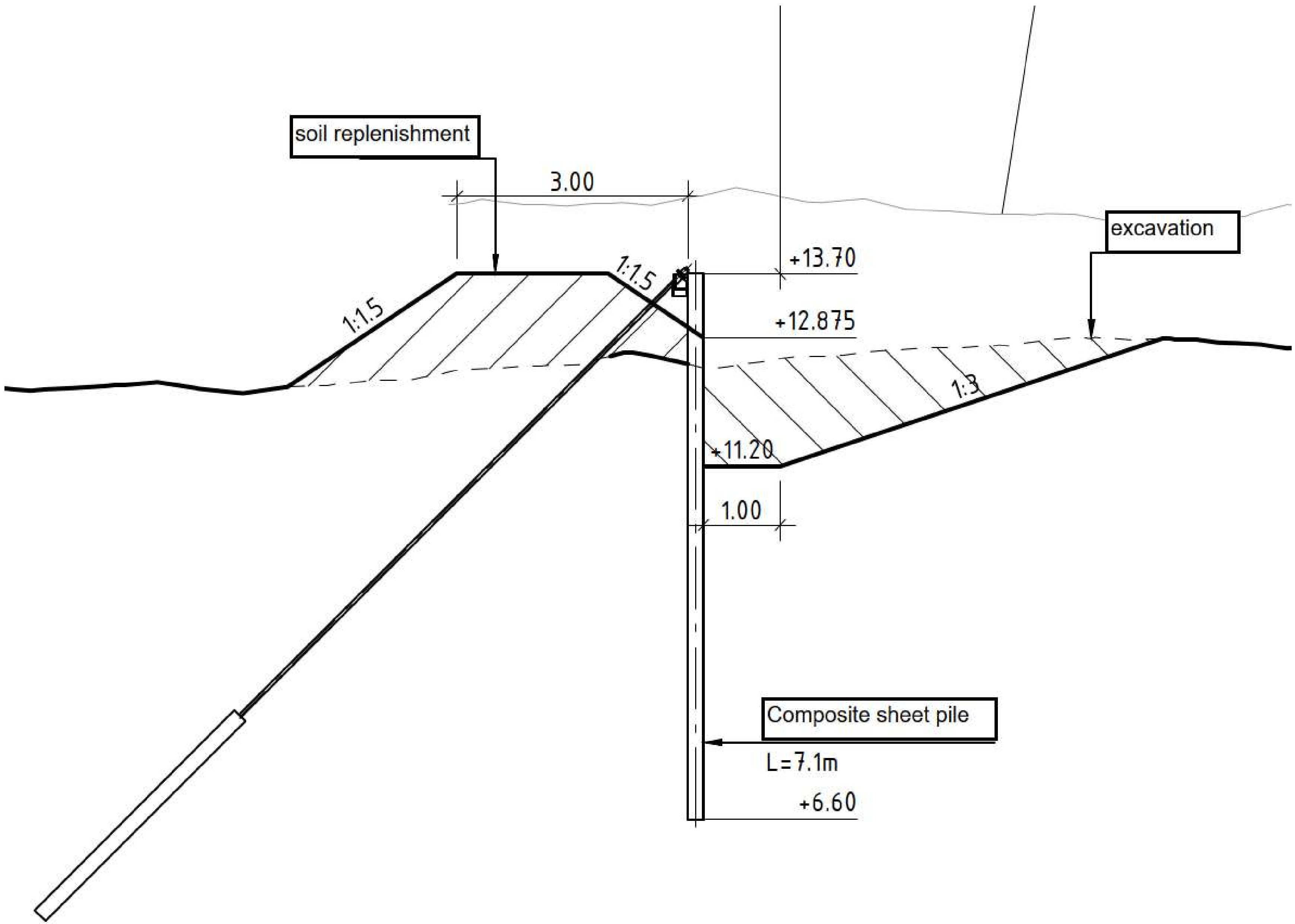
NULMETING na test 1	x [mm]	y [mm]	z [mm]	Time and date
1	55111	10456	898	12-6-2023 10:11
2	55113	10490	3178	12-6-2023 10:11
3	57820	10417	858	12-6-2023 10:12
4	57834	10471	3175	12-6-2023 10:13
5	60560	10407	855	12-6-2023 10:14
6	60563	10449	3175	12-6-2023 10:15
11	68778	10477	896	12-6-2023 10:15
12	68785	10498	3188	12-6-2023 10:16
13	71516	10468	938	12-6-2023 10:16
14	71530	10495	3174	12-6-2023 10:17
15	74254	10483	848	12-6-2023 10:17
16	74251	10485	3180	12-6-2023 10:18
21	79754	10489	855	12-6-2023 10:18
22	79752	10473	3207	12-6-2023 10:19
23	82490	10465	902	12-6-2023 10:20
24	82493	10490	3195	12-6-2023 10:20
25	85228	10473	891	12-6-2023 10:21
26	85231	10500	3180	12-6-2023 10:21
1_begin	55111	10455	898	12-6-2023 10:28
2_begin	55113	10489	3178	12-6-2023 10:29
3_begin	57820	10416	858	12-6-2023 10:29
4_begin	57834	10470	3175	12-6-2023 10:30
5_begin	60560	10405	854	12-6-2023 10:30
6_begin	60562	10448	3174	12-6-2023 10:31
11_begin	68778	10476	896	12-6-2023 10:32
12_begin	68786	10497	3187	12-6-2023 10:32
13_begin	71516	10467	938	12-6-2023 10:33
14_begin	71529	10494	3173	12-6-2023 10:33
15_begin	74254	10482	848	12-6-2023 10:34
16_begin	74252	10484	3180	12-6-2023 10:34
21_begin	79754	10488	855	12-6-2023 10:35
22_begin	79752	10472	3207	12-6-2023 10:35
23_begin	82491	10464	902	12-6-2023 10:36
24_begin	82494	10489	3195	12-6-2023 10:36
25_begin	85228	10472	890	12-6-2023 10:37
26_begin	85232	10507	3179	12-6-2023 10:37

Pressure [kN]	x [mm]	y [mm]	z [mm]	Time and date
1_5kn	55111	10455	898	12-6-2023 10:43
2_5kn	55112	10483	3178	12-6-2023 10:44
3_5kn	57821	10416	858	12-6-2023 10:44
4_5kn	57834	10464	3175	12-6-2023 10:45
5_5kn	60560	10405	855	12-6-2023 10:45
6_5kn	60563	10441	3175	12-6-2023 10:46
1_15kn	55111	10455	897	12-6-2023 10:48
2_15kn	55111	10480	3178	12-6-2023 10:48
3_15kn	57821	10416	858	12-6-2023 10:49
4_15kn	57834	10461	3175	12-6-2023 10:50
5_15kn	60561	10405	855	12-6-2023 10:50
6_15kn	60563	10440	3175	12-6-2023 10:50
1_20kn	55110	10455	898	12-6-2023 10:52
2_20kn	55111	10479	3178	12-6-2023 10:52
3_20kn	57821	10416	858	12-6-2023 10:53
4_20kn	57834	10460	3175	12-6-2023 10:53
5_20kn	60561	10405	854	12-6-2023 10:54
6_20kn	60563	10438	3175	12-6-2023 10:54
12_20kn	68786	10497	3187	12-6-2023 10:55
14_20kn	71530	10493	3173	12-6-2023 10:55
120603	94698	14249	3564	12-6-2023 11:00
1_25kn	55111	10454	897	12-6-2023 11:01
2_25kn	55112	10477	3178	12-6-2023 11:01
3_25kn	57821	10415	858	12-6-2023 11:02
4_25kn	57834	10458	3175	12-6-2023 11:02
5_25kn	60561	10405	855	12-6-2023 11:03
6_25kn	60563	10436	3175	12-6-2023 11:03
11_25kn	68778	10475	895	12-6-2023 11:04
12_25kn	68786	10496	3187	12-6-2023 11:04
1_30kn	55111	10455	897	12-6-2023 11:05
2_30kn	55112	10476	3178	12-6-2023 11:06
3_30kn	57821	10416	858	12-6-2023 11:06
4_30kn	57834	10457	3175	12-6-2023 11:07
5_30kn	60561	10405	854	12-6-2023 11:07
6_30kn	60564	10434	3175	12-6-2023 11:08
11_30kn	68778	10475	896	12-6-2023 11:08
12_30kn	68786	10496	3187	12-6-2023 11:09
13_30kn	71516	10466	937	12-6-2023 11:09
1_35kn	55111	10455	897	12-6-2023 11:10
2_35kn	55111	10475	3178	12-6-2023 11:11
3_35kn	57821	10415	858	12-6-2023 11:11
4_35kn	57834	10455	3175	12-6-2023 11:12

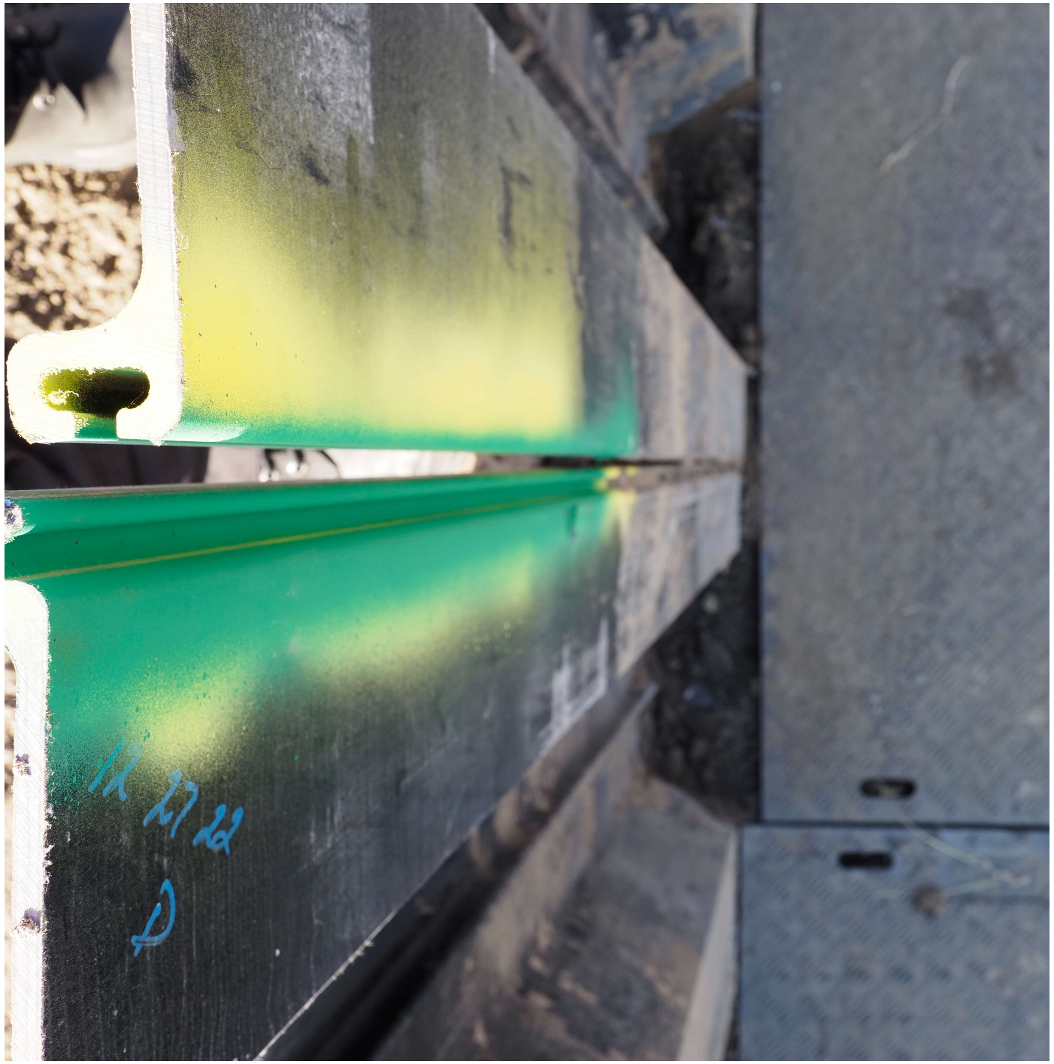
5_35kn	60561	10405	854	12-6-2023 11:12
6_35kn	60564	10434	3175	12-6-2023 11:13
11_35kn	68778	10475	895	12-6-2023 11:13
12_35kn	68786	10496	3186	12-6-2023 11:14
13_35kn	71516	10466	937	12-6-2023 11:14
14_35kn	71530	10493	3173	12-6-2023 11:15
1_40kn	55111	10454	897	12-6-2023 11:16
2_40kn	55112	10479	3178	12-6-2023 11:16
3_40kn	57821	10416	858	12-6-2023 11:16
4_40kn	57834	10454	3175	12-6-2023 11:17
5_40kn	60561	10405	855	12-6-2023 11:17
6_40kn	60562	10433	3175	12-6-2023 11:18
11_40kn	68778	10475	896	12-6-2023 11:18
12_40kn	68786	10496	3187	12-6-2023 11:19
13_40kn	71516	10466	937	12-6-2023 11:19
14_40kn	71530	10493	3173	12-6-2023 11:20
15_40kn	74254	10482	848	12-6-2023 11:21
16_40kn	74252	10484	3179	12-6-2023 11:21
21_40kn	79754	10488	854	12-6-2023 11:22
22_40kn	79752	10471	3206	12-6-2023 11:22
23_40kn	82491	10463	902	12-6-2023 11:23
24_40kn	82494	10488	3194	12-6-2023 11:23
25_40kn	85228	10471	890	12-6-2023 11:24
26_40kn	85232	10507	3179	12-6-2023 11:24
Zonder druk				
1_eind	55112	10455	898	12-6-2023 11:32
2_eind	55111	10484	3178	12-6-2023 11:32
3_eind	57821	10415	858	12-6-2023 11:33
4_eind	57833	10465	3175	12-6-2023 11:36
5_eind	60561	10404	854	12-6-2023 11:37
6_eind	60562	10444	3174	12-6-2023 11:37
11_eind	68778	10475	896	12-6-2023 11:38
12_eind	68787	10497	3186	12-6-2023 11:38
13_eind	71516	10466	937	12-6-2023 11:39
14_eind	71530	10493	3173	12-6-2023 11:39
15_eind	74254	10481	848	12-6-2023 11:40
16_eind	74252	10484	3179	12-6-2023 11:40
21_eind	79755	10487	855	12-6-2023 11:41
22_eind	79752	10471	3206	12-6-2023 11:42
23_eind	82491	10463	902	12-6-2023 11:42
24_eind	82494	10488	3195	12-6-2023 11:43
25_eind	85229	10471	890	12-6-2023 11:43
26_eind	85232	10507	3179	12-6-2023 11:43

11.7 Appendix G – Presentation results and test

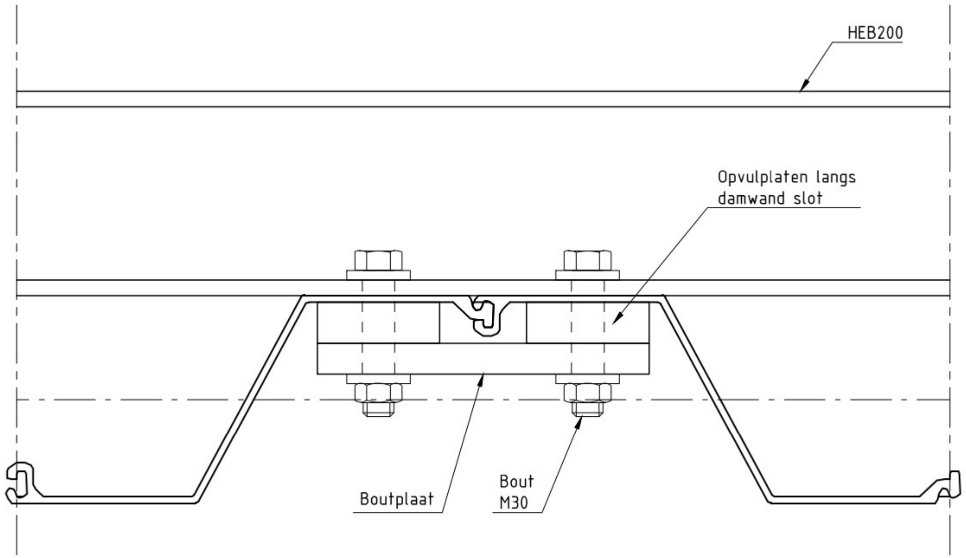
Test location



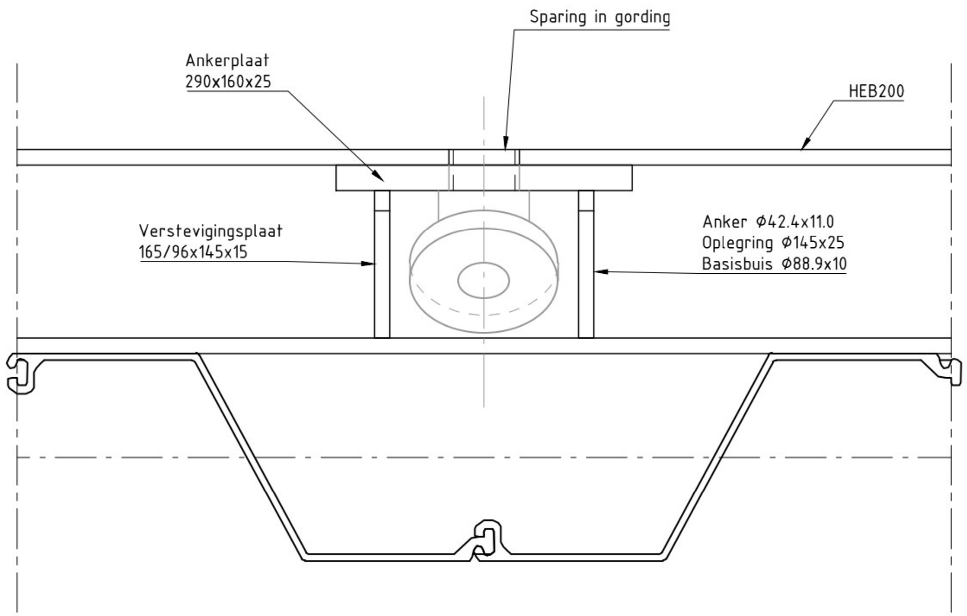
soil replenishment
3.00
1:1.5
1:1.5
+13.70
+12.875
excavation
1:3
+11.20
1.00
Composite sheet pile
L=7.1m
+6.60



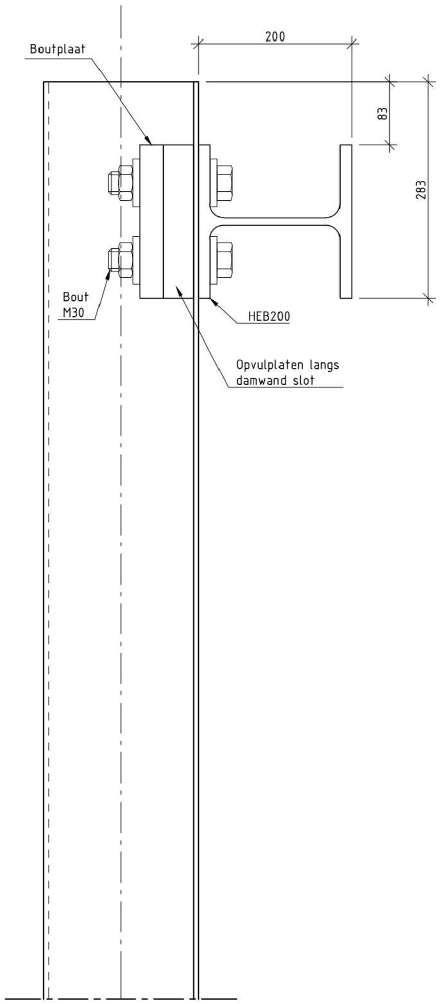
Option 1 – test location 3



BOVENAANZICHT BOUTPLAAT
Schaal 1: 5

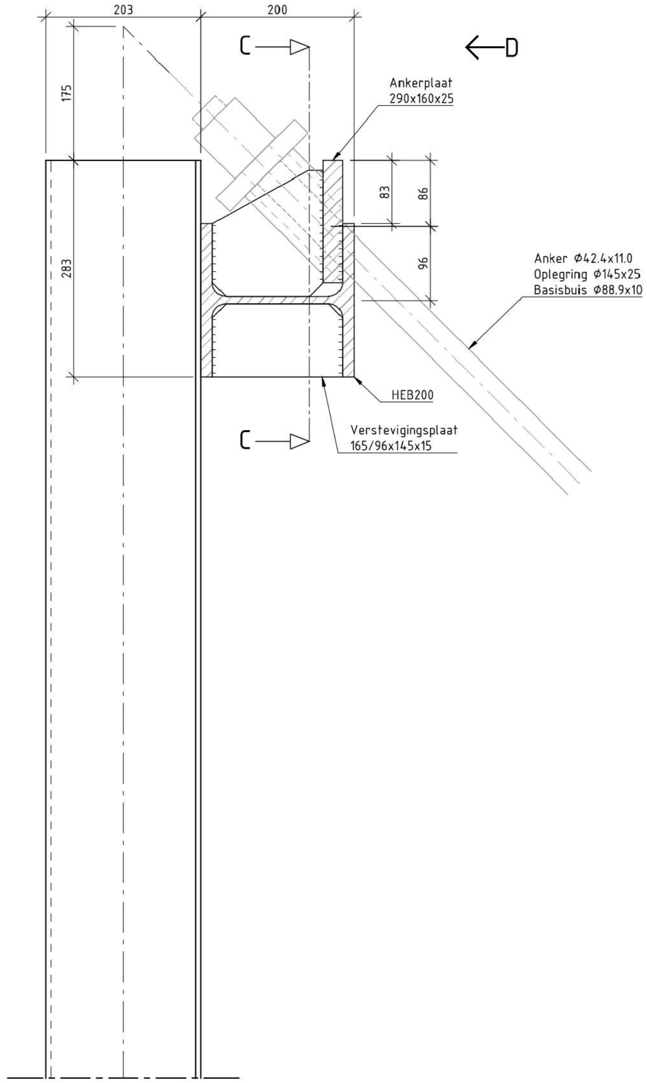


BOVENAANZICHT ANKERSTOEL
Schaal 1: 5



DOORSNEDE A-A

Schaal 1: 5



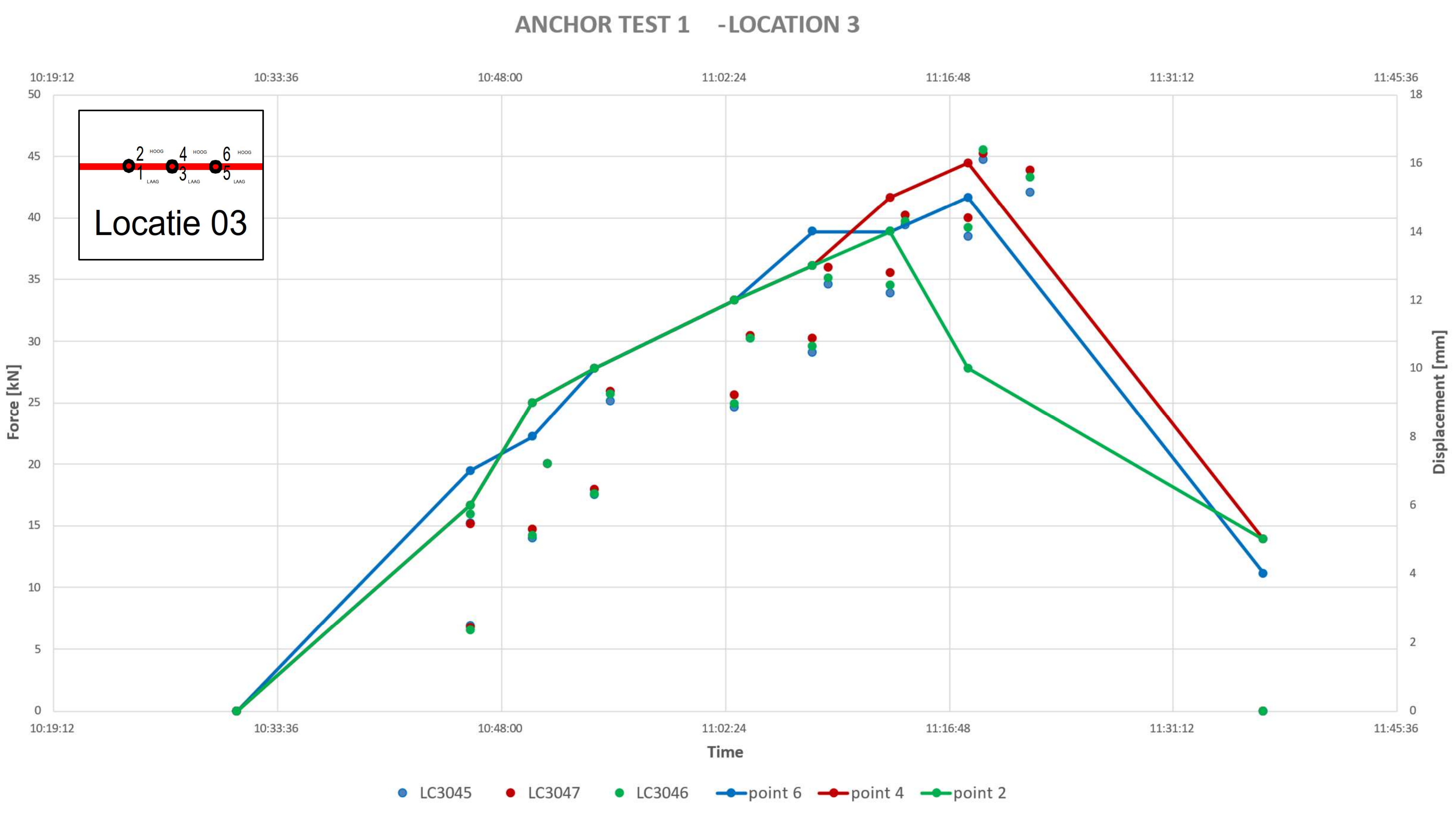
DOORSNEDE B-B

Schaal 1: 5



03


LC3045



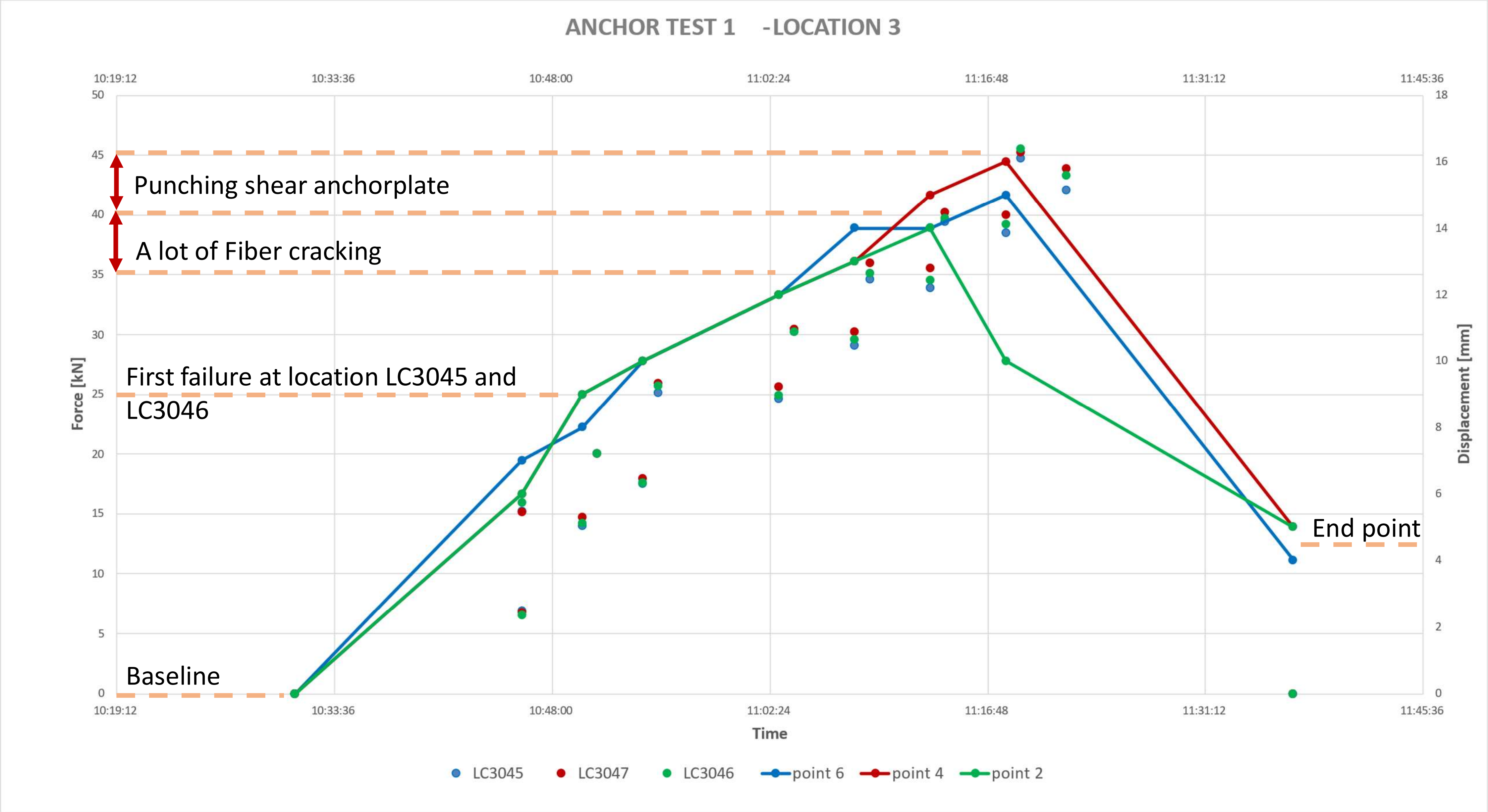
ANCHOR TEST 1 -LOCATION 3
Locatie 03
2 HOOG
4 HOOG
6 HOOG
1 LAAG
3 LAAG
5 LAAG
Force [kN]
Displacement [mm]
Time
10:19:12
10:33:36
10:48:00
11:02:24
11:16:48
11:31:12
11:45:36
0
5
10
15
20
25
30
35
40
45
50
0
2
4
6
8
10
12
14
16
18
LC3045
LC3047
LC3046
point 6
point 4
point 2

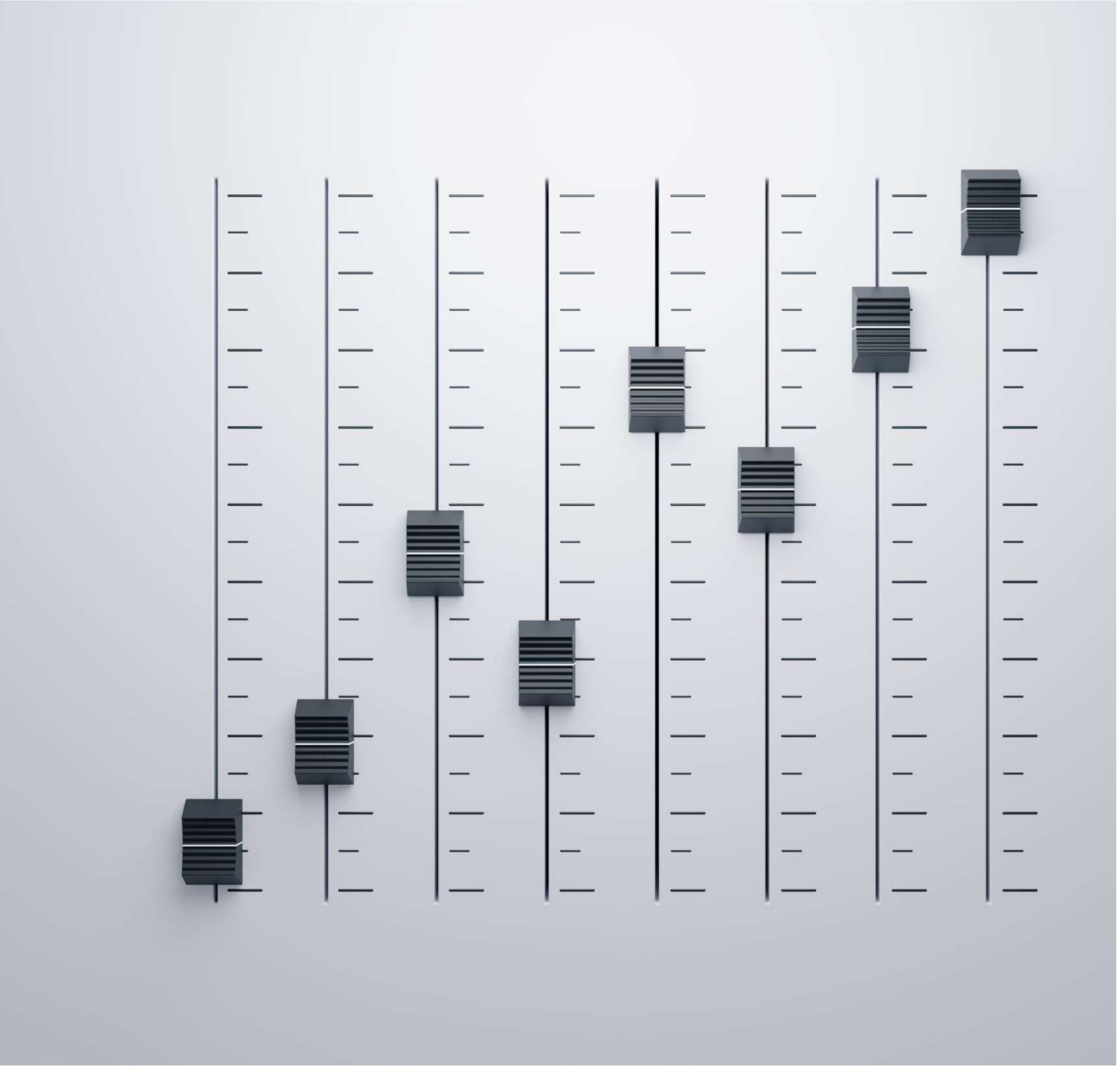
Test 1 location 3

When increasing the screw force from 25 kN to 30 kN, a creaking sound from the sheet pile is observed, and initial damage (first failure) is noted in in the connection plates left and right from hydraulic jacks LC3045 and LC3046.

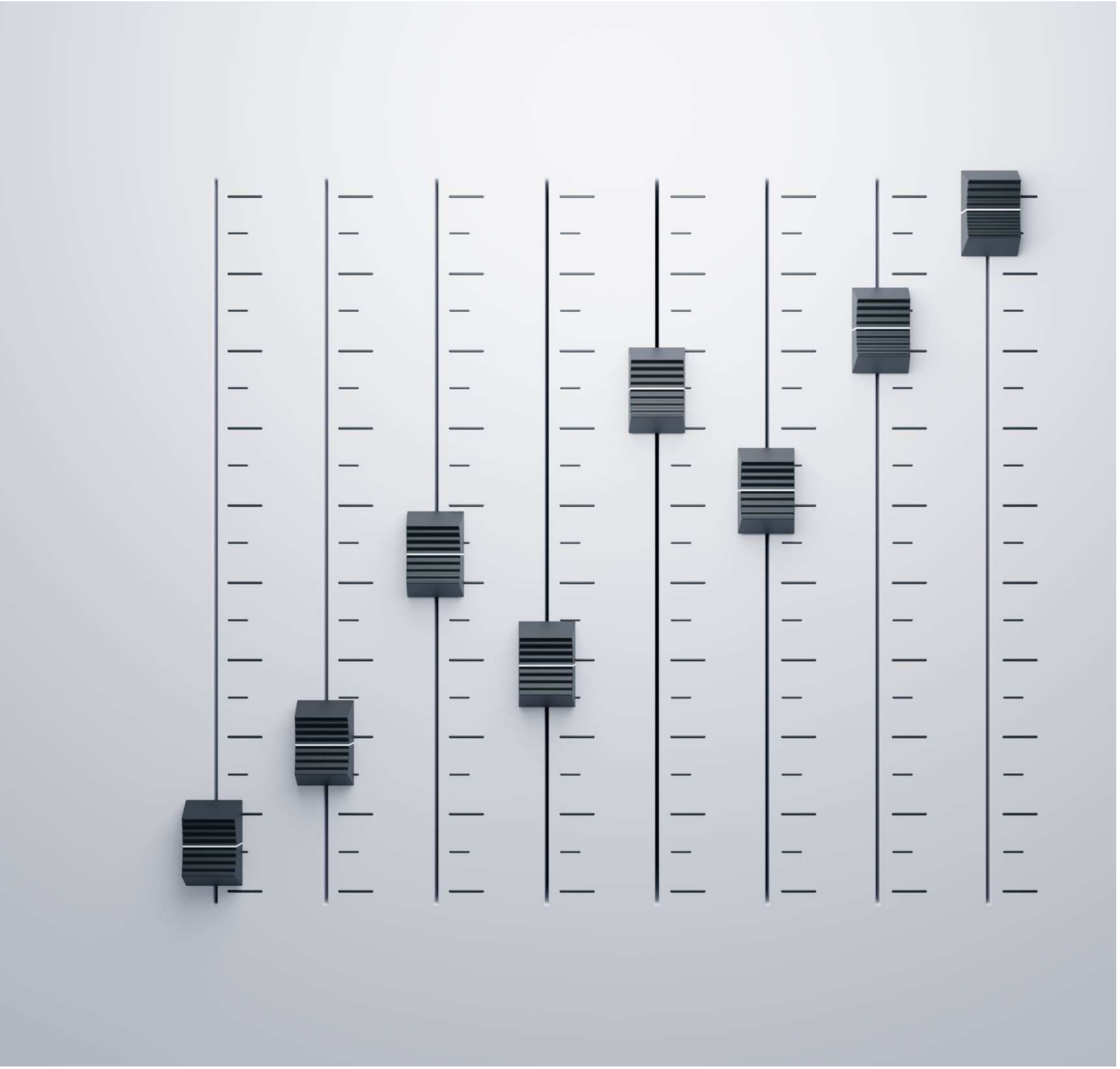
At 35 kN, the sound of fiber breakage becomes very noticeable;

The sheet pile around the connection plates left and right from LC3045 are the first to fully fail due to punching shear under a maximum force of 45 kN.


ANCHOR TEST 1 -LOCATION 3
Punching shear anchorplate
A lot of Fiber cracking
First failure at location LC3045 and LC3046
Baseline
End point
Force [kN]
Displacement [mm]
Time
10:19:12
10:33:36
10:48:00
11:02:24
11:16:48
11:31:12
11:45:36
0
5
10
15
20
25
30
35
40
45
50
0
2
4
6
8
10
12
14
16
18
LC3045
LC3047
LC3046
point 6
point 4
point 2



Sound creep composite



Sound failure composite

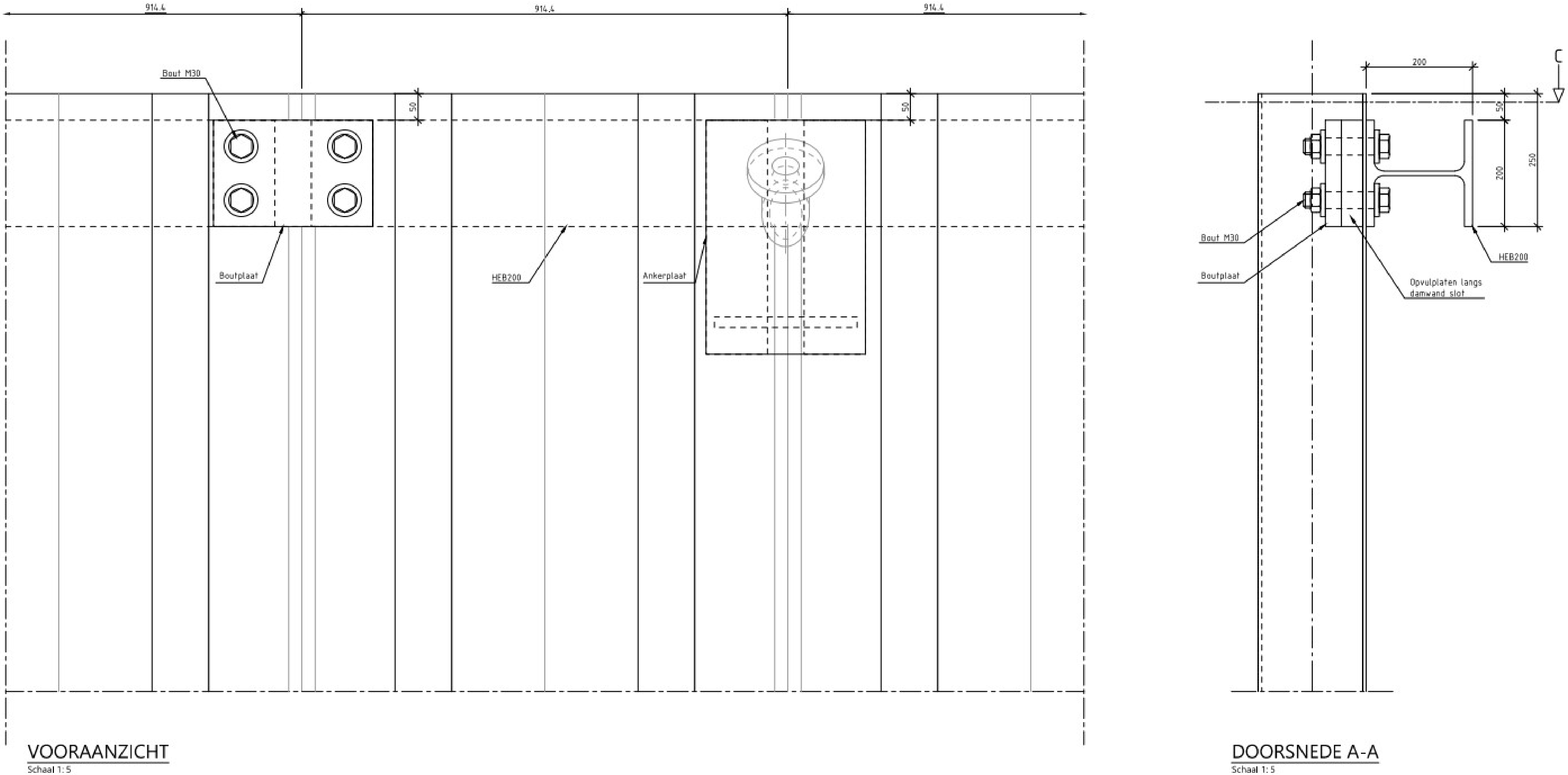

XYLX
8.8U
XYLX
8.8U

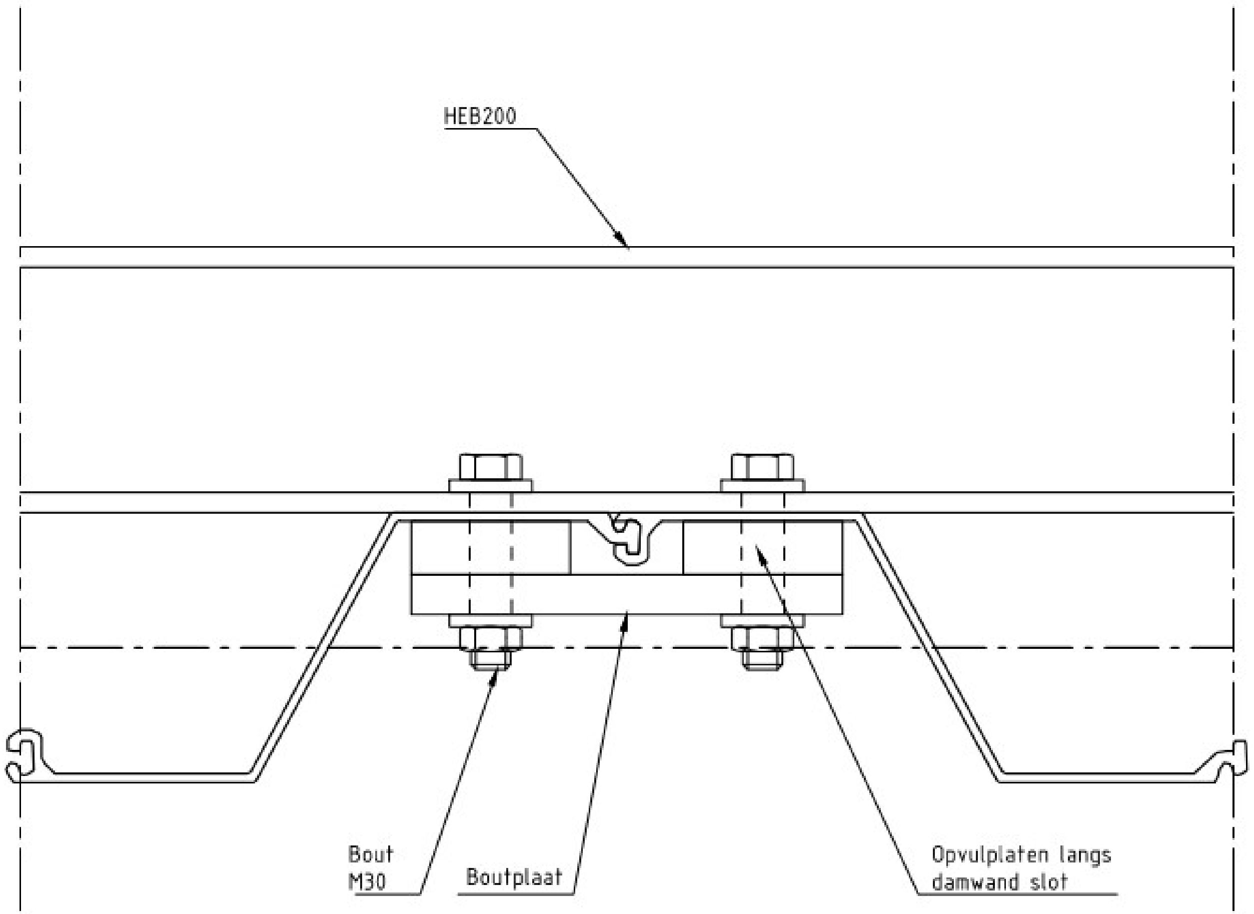

Laco Rotterdam bv

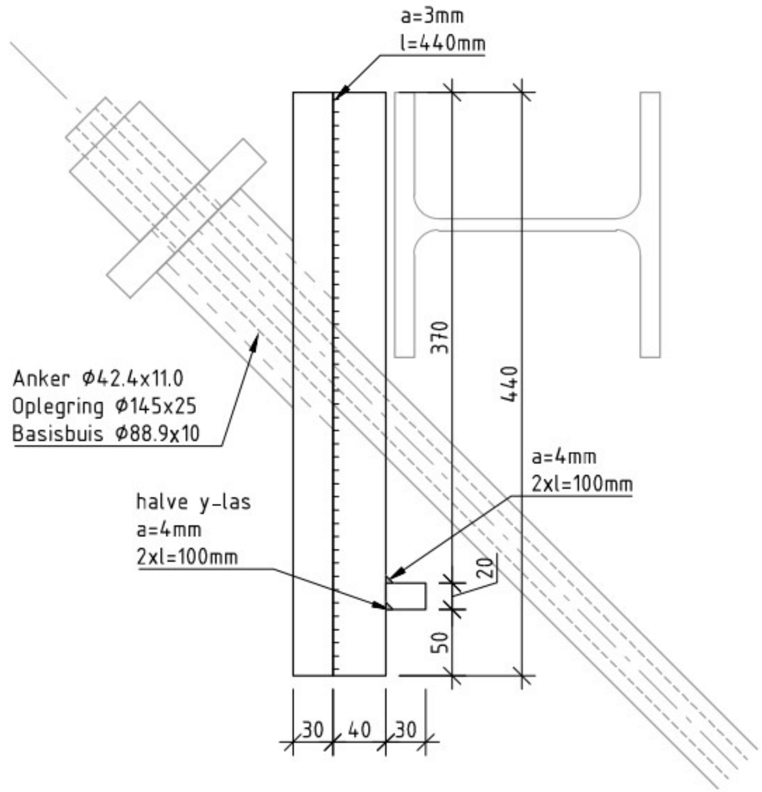

03


03

Option 2 – Test location 2

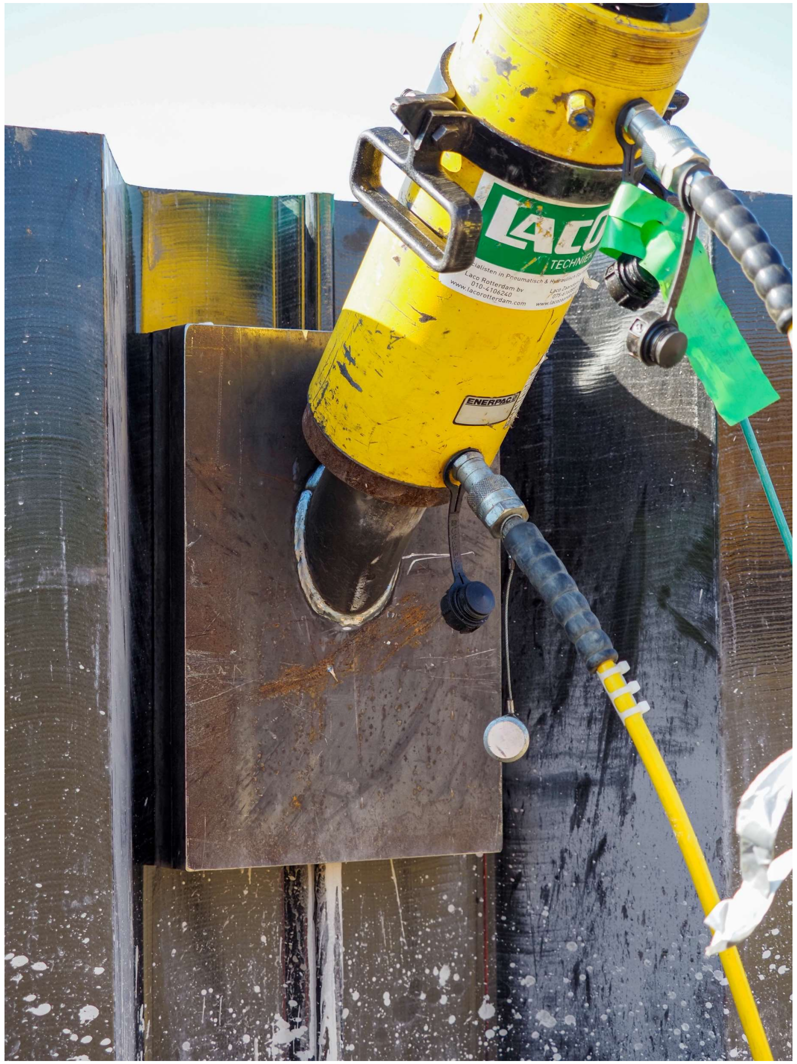


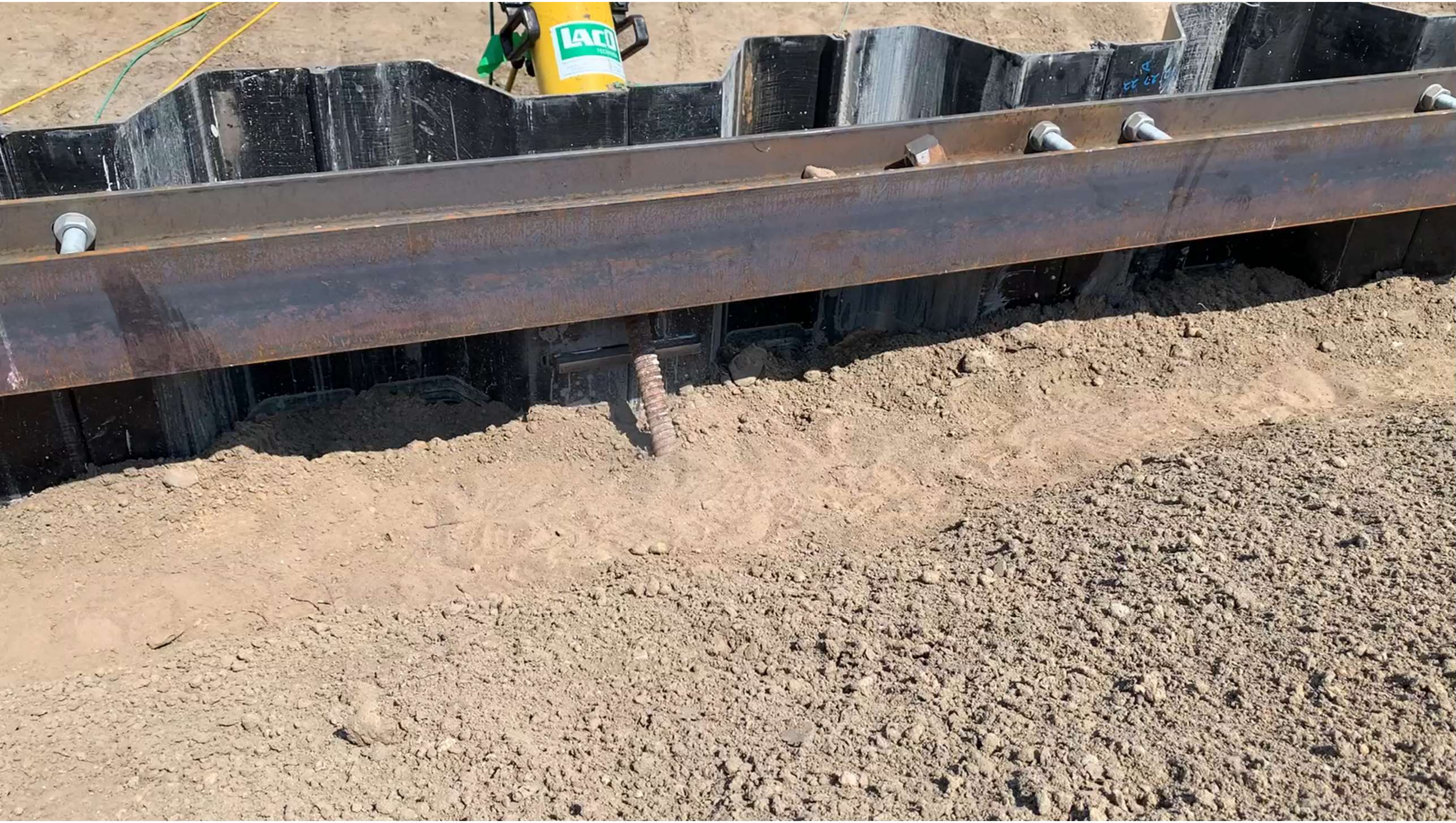




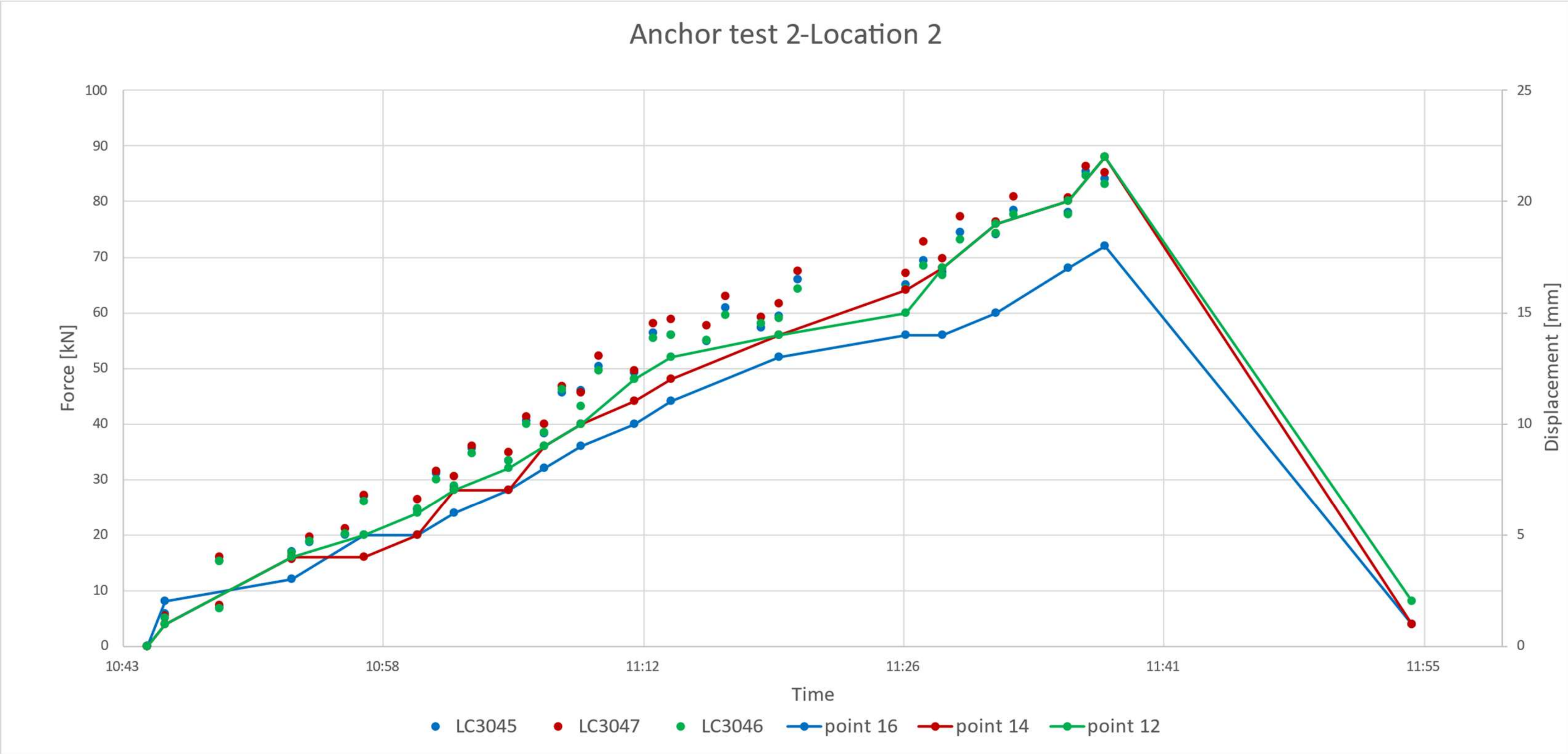
ANKERSTOEL

Schaal 1: 5
Zijaanzicht


TECHNIEK
Laco Rotterdam bv
010-4106240
www.lacorotterdam.com
ENERPAC


LACO


Laco Rotterdam bv
010-4106240
www.lacorotterdam.com

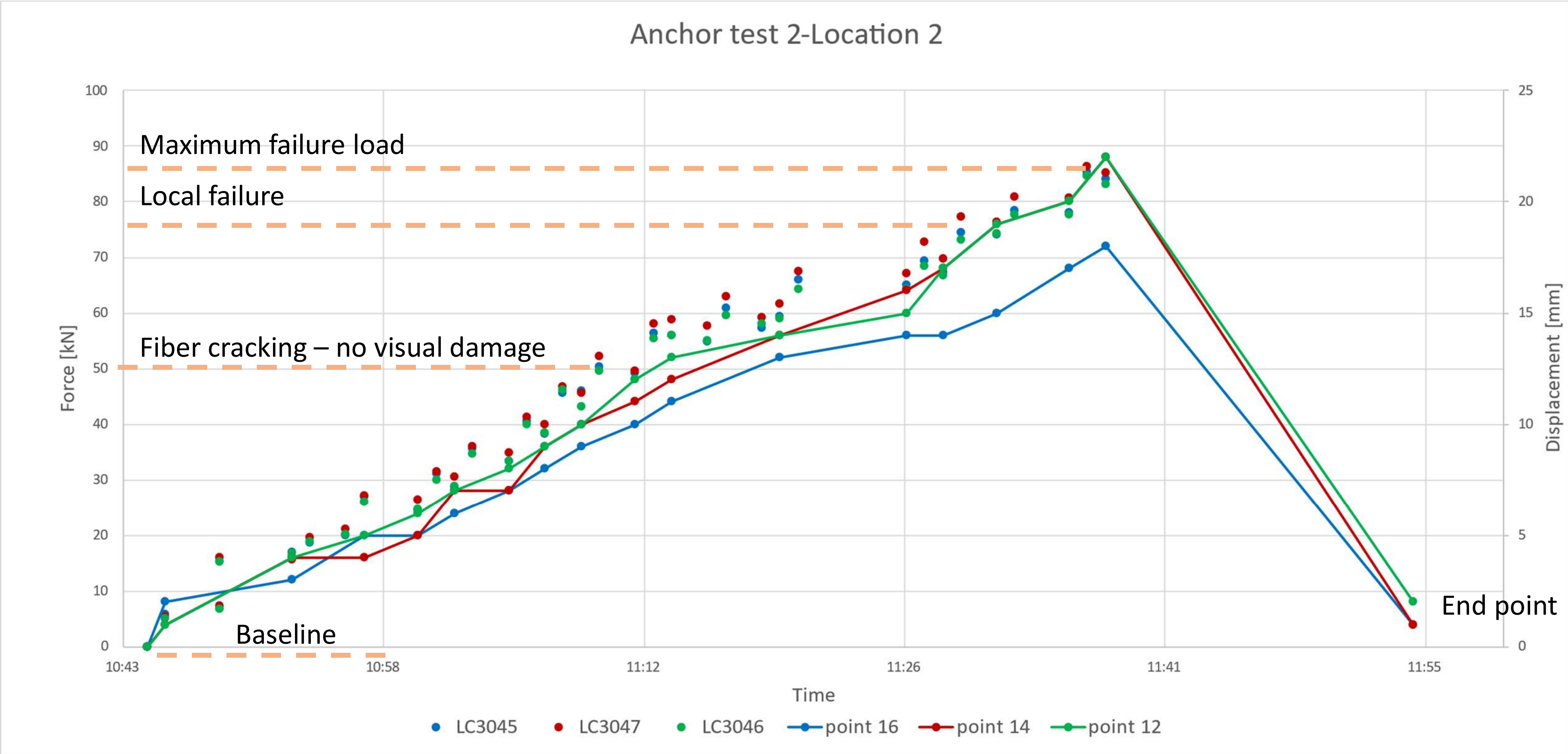


Anchor test 2-Location 2
Force [kN]
Displacement [mm]
Time
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
10:43
10:58
11:12
11:26
11:41
11:55
LC3045
LC3047
LC3046
point 16
point 14
point 12

Test variant 2 location 2

Fiber breakage is audible at 55 kN
(not visually observed).

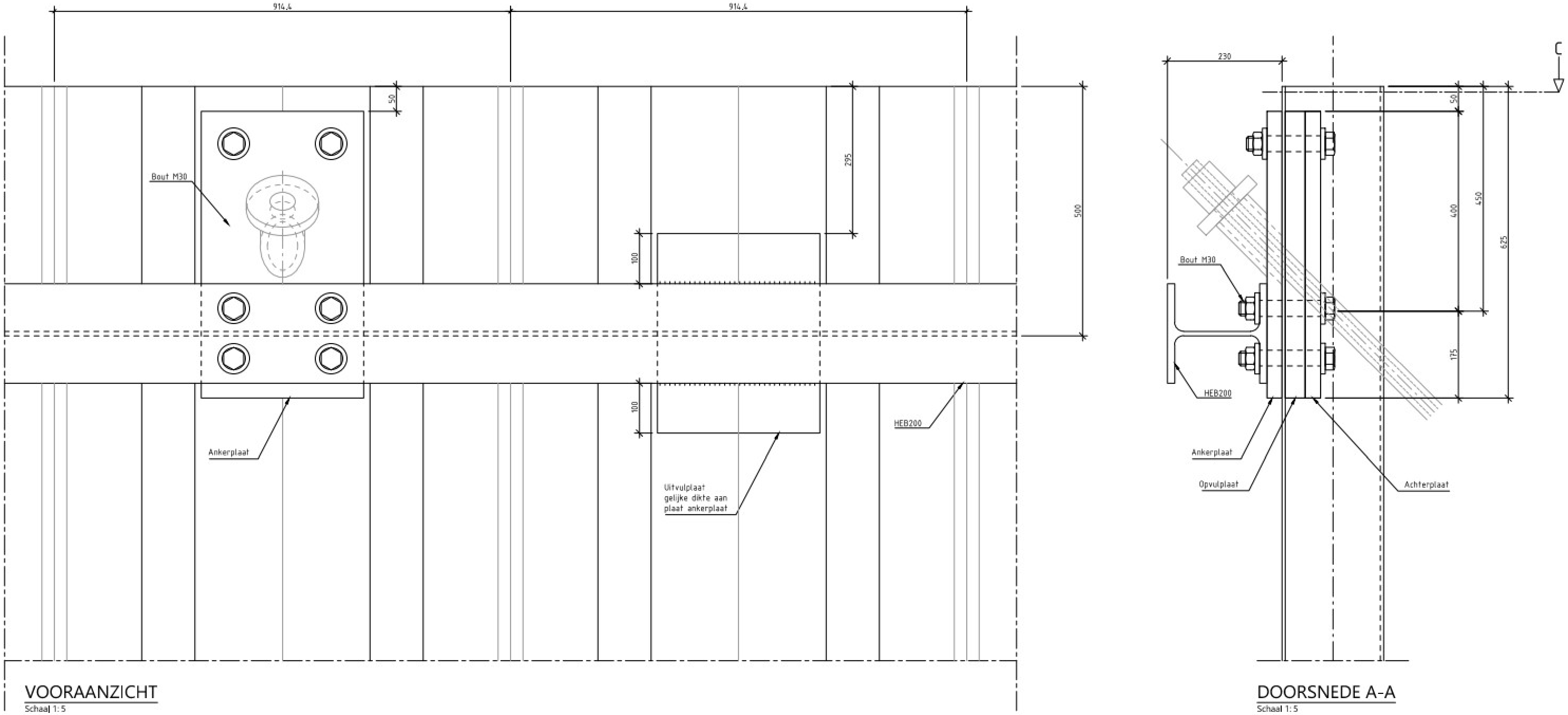
Local failure occurs at 75 kN;

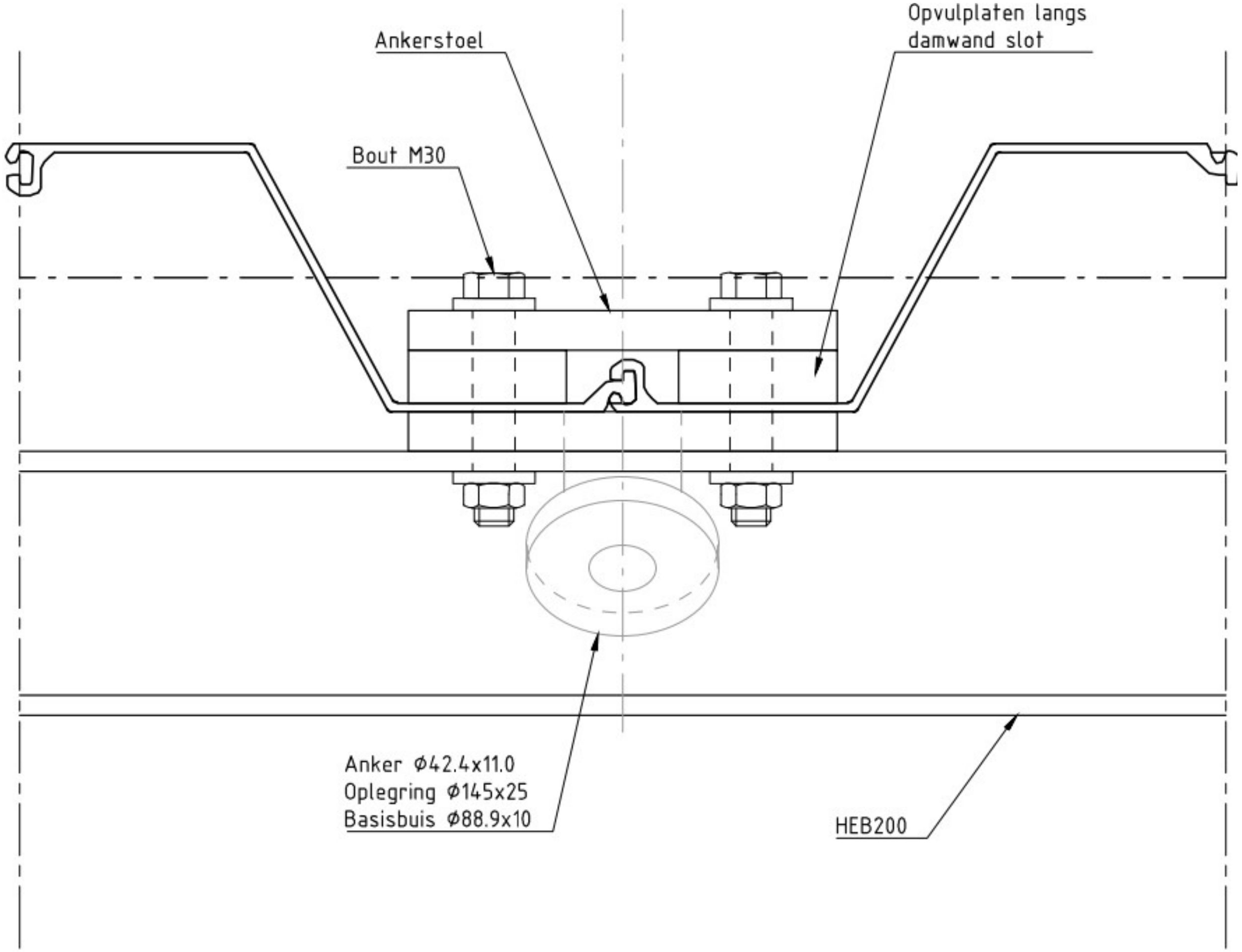
The maximum absorbable force is 85 kN

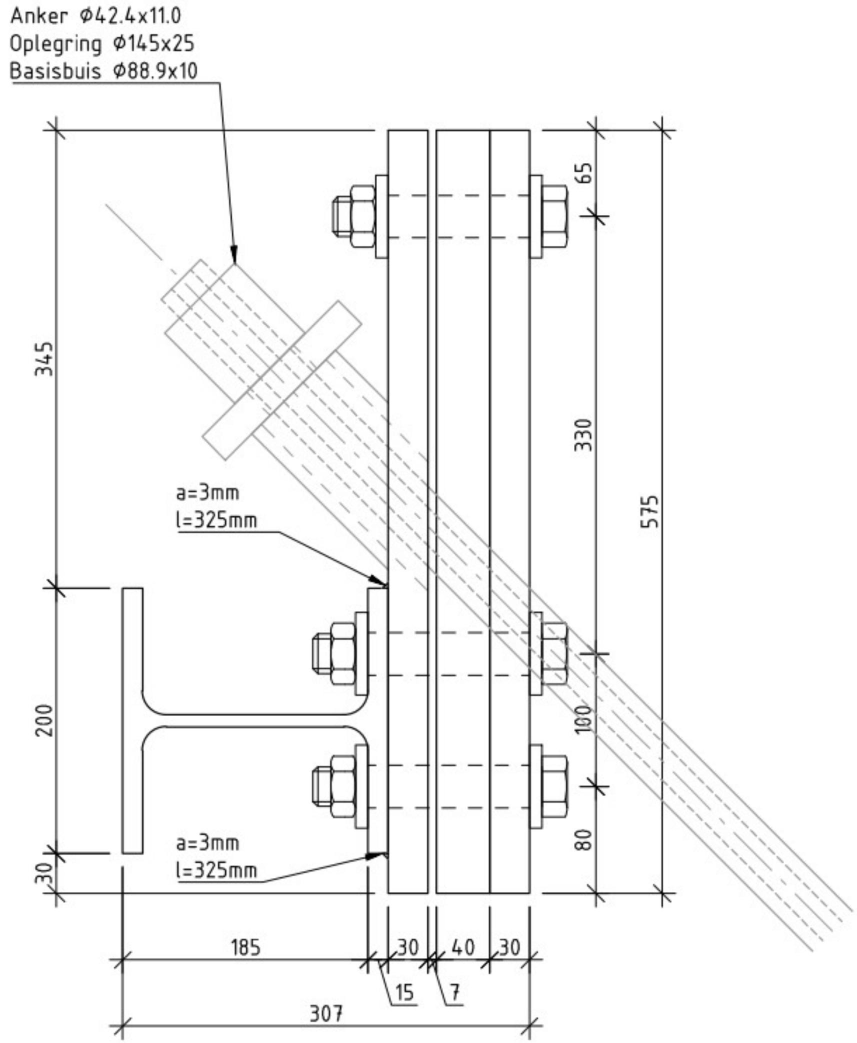


Anchor test 2-Location 2
Maximum failure load
Local failure
Fiber cracking – no visual damage
Baseline
End point
Force [kN]
Displacement [mm]
Time
100
90
80
70
60
50
40
30
20
10
0
25
20
15
10
5
0
10:43
10:58
11:12
11:26
11:41
11:55
LC3045
LC3047
LC3046
point 16
point 14
point 12

Option 3 – Test location 1



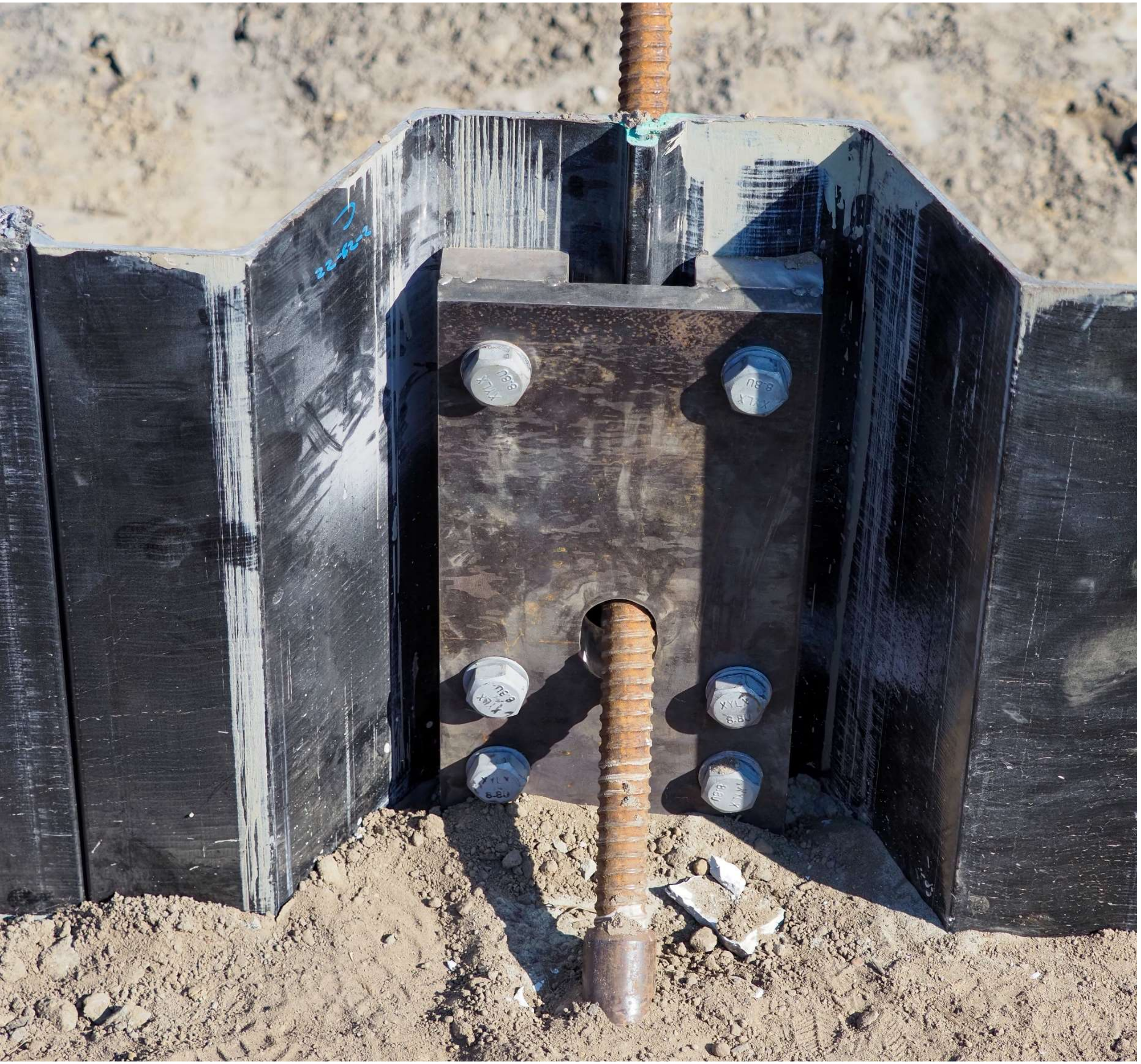


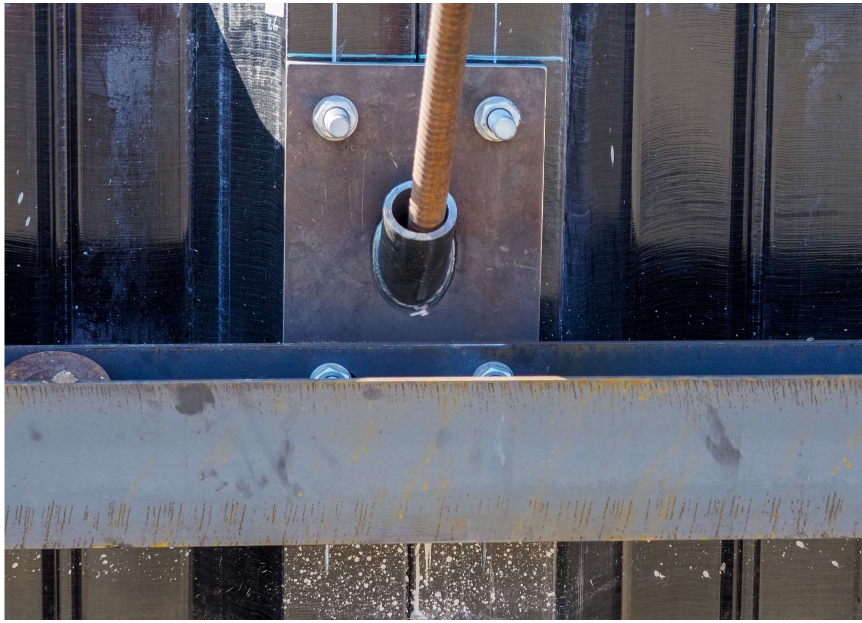


ANKERSTOEL

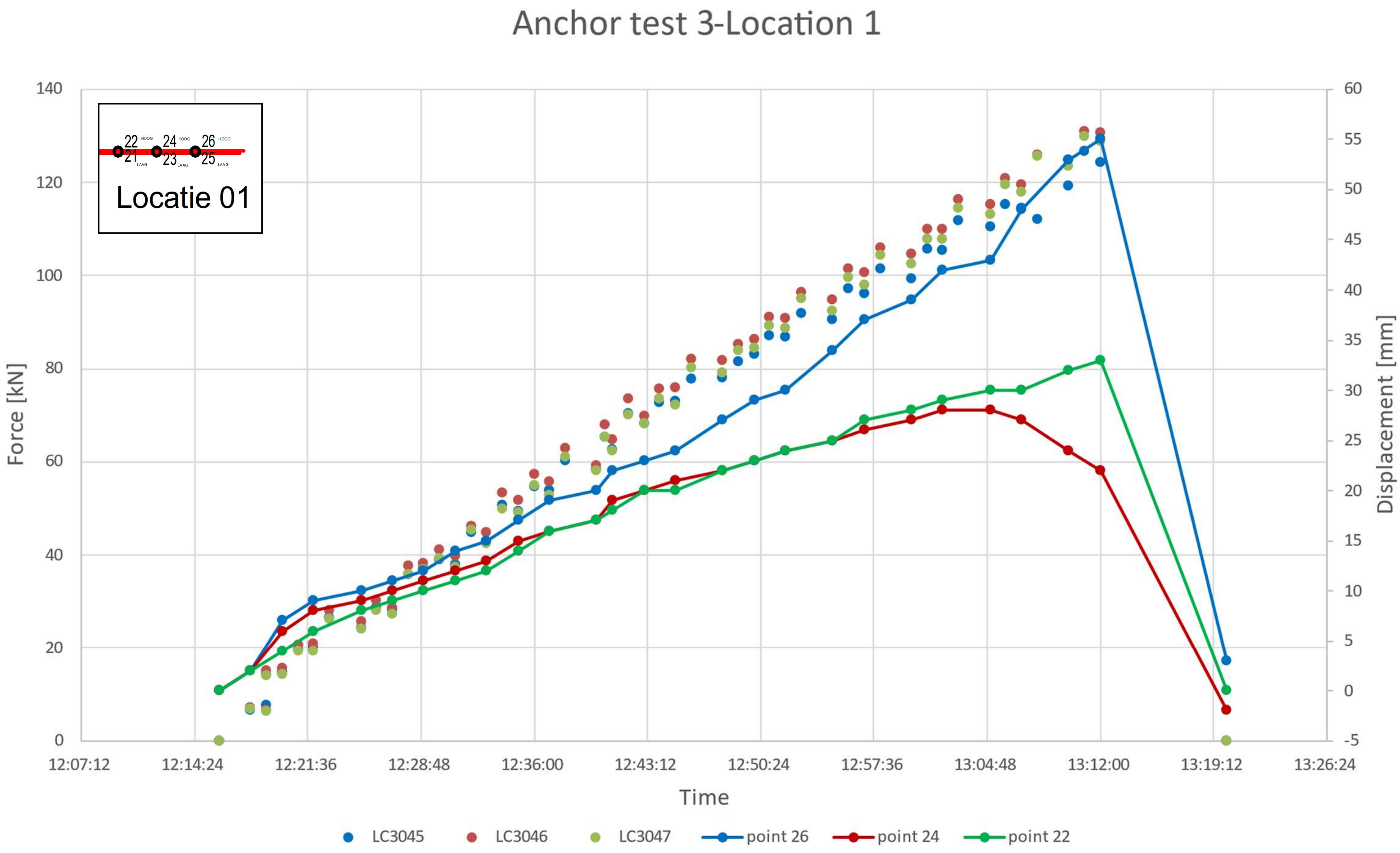
Schaal 1: 5

Zijaanzicht






ENERPAC



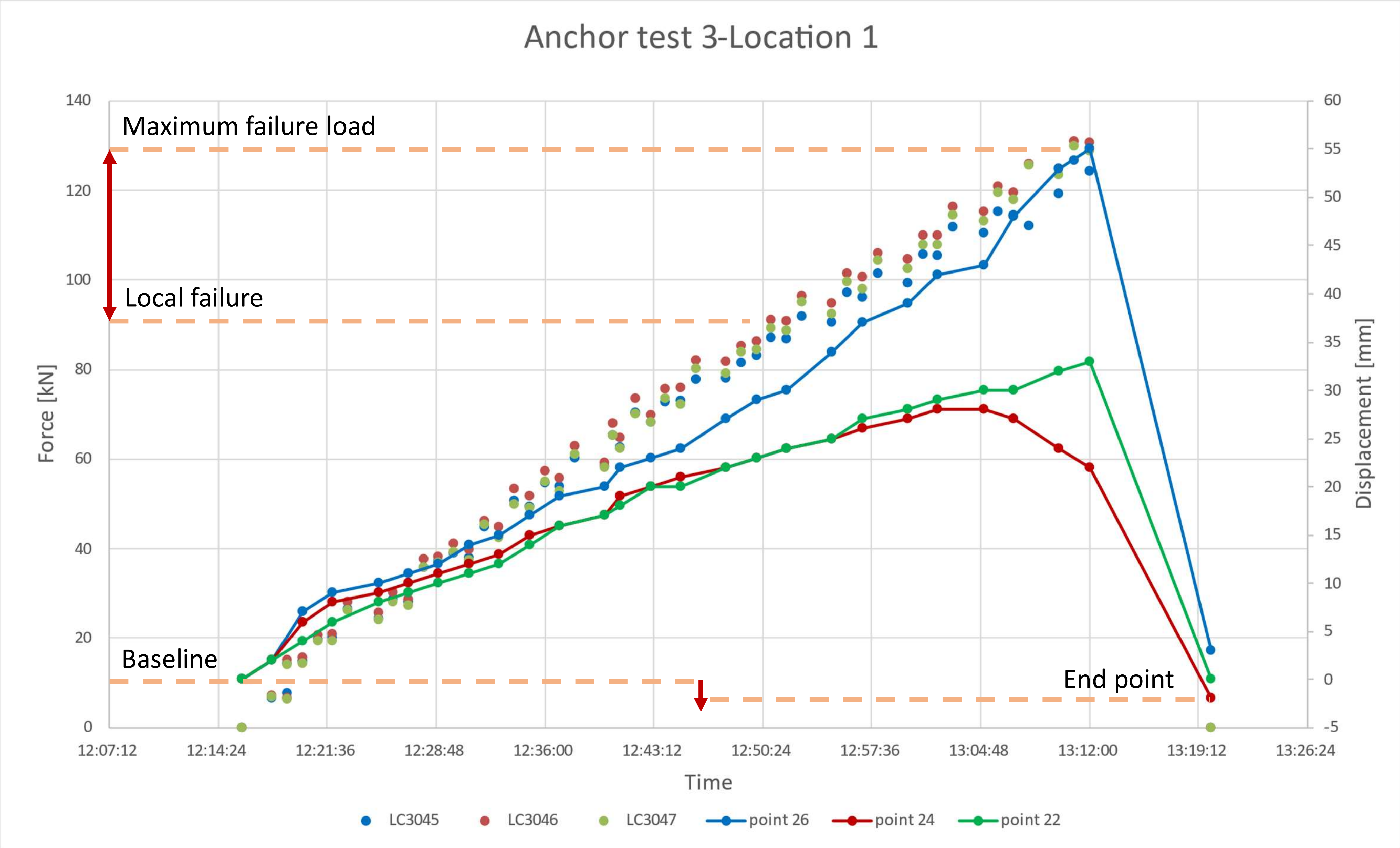
Anchor test 3-Location 1
22 HOOG
24 HOOG
26 HOOG
21 LAAG
23 LAAG
25 LAAG
Locatie 01
Force [kN]
0
20
40
60
80
100
120
140
Displacement [mm]
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Time
12:07:12
12:14:24
12:21:36
12:28:48
12:36:00
12:43:12
12:50:24
12:57:36
13:04:48
13:12:00
13:19:12
13:26:24
LC3045
LC3046
LC3047
point 26
point 24
point 22

Test variant 3 location 1

In this variant, the least fiber breakage is audible and only occurs at a very high hydraulic jack pressure;

Local failure occurs at 90 kN;

The maximum absorbable force is 127 kN


Anchor test 3-Location 1
Maximum failure load
Local failure
Baseline
End point
Force [kN]
Displacement [mm]
Time
140
120
100
80
60
40
20
0
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
12:07:12
12:14:24
12:21:36
12:28:48
12:36:00
12:43:12
12:50:24
12:57:36
13:04:48
13:12:00
13:19:12
13:26:24
LC3045
LC3046
LC3047
point 26
point 24
point 22