Appendix C

Results Field Test Waddensea dike

Tests executed between: March & April 2019.

TU Delft Delft University of Technology

INFRAM HYDREN Hydraulic Engineering, Innovation & Research

Contents

Introduction

This appendix presents the test results of the direct pull tests executed with the grass sod pulling device. The test results are the basis of the study into the Strength of Grass Covers on Dikes. The tests presented in this appendix were executed on the Waddensea dike near Oosterbierum at the location with the following coordinates: 53°14’32.6"N 5°29’29.4"E. The grass cover coverage at this location was of an excellent quality and the subsoil is characterised as clay with a low sand content.

The objective of the field tests was to gain insights into the mechanical behaviour of the grass cover. The influence of the following processes were tested:

1. Tensile behaviour of cohesive sediments.
2. Tensile behaviour of grass roots.
3. Fatigue of the grass cover.

To test the influence of these processes, the following three different load regimes were designed: stepwise increased constant load, stepwise increased cyclic load and maximum force load. For each load regime, the analysis method was based on different metrics as summarized below:

1. Stepwise increased constant load.
    - Measurement of load and displacement.
    - Resulting elasticity.
    - Stress - Strain relation.
    - E modulus based on the final displacement induced by a constant load.
    - Time to reach 80% of the final displacement induced by a constant load.
2. Stepwise increased cyclic load.
    - Measurement of load and displacement.
    - Resulting elasticity per cycle.
    - Displacement per cycle.
    - Resulting total and partial elasticity per cycle.
    - Growth rate of the plastic and elastic deformation.
    - Growth rate of the elasticity.
3. Maximum force load.
    - Measurement of load and displacement.
    - Stress - Strain relation.

For each test, the dimensions and pictures of the tested grass cover sample are presented together with the metrics associated with the tested load regime.

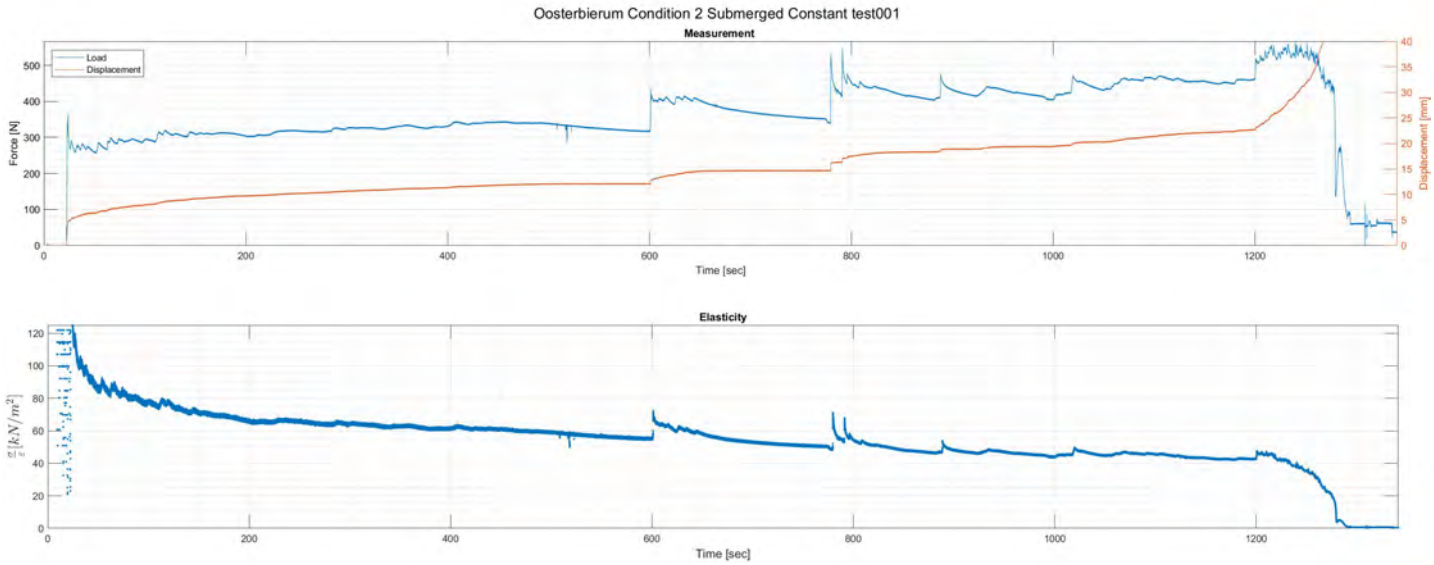
Submerged Condition 2 Constant

	Time to reach 80% of displacement $[sec]$	$E\,[kN/m^2]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test008	58	47.70	5.9	25.0	10.5	4.0
test007	73	43.37	5.7	24.0	7.4	4.0
test006	19	27.76	7.0	28.0	9.7	4.3
test004	153	26.25	2.4	24.0	7.7	4.6
test003	126	33.87	6.9	26.0	9.6	2.6
test002	44	39.36	7.4	30.0	9.8	6.8
test001	155	55.58	6.4	25.0	11.7	7.6
mean	90	39.13	6.0	26.0	9.5	4.8
median	73	39.36	6.4	25.0	9.7	4.3
75th percentile	146	46.62	7.0	27.5	10.3	6.3
25th percentile	48	29.29	5.7	24.3	8.2	4.0

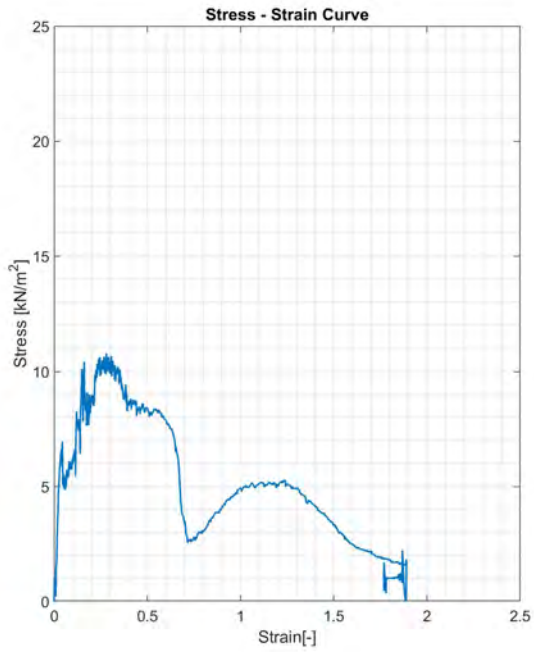
test001

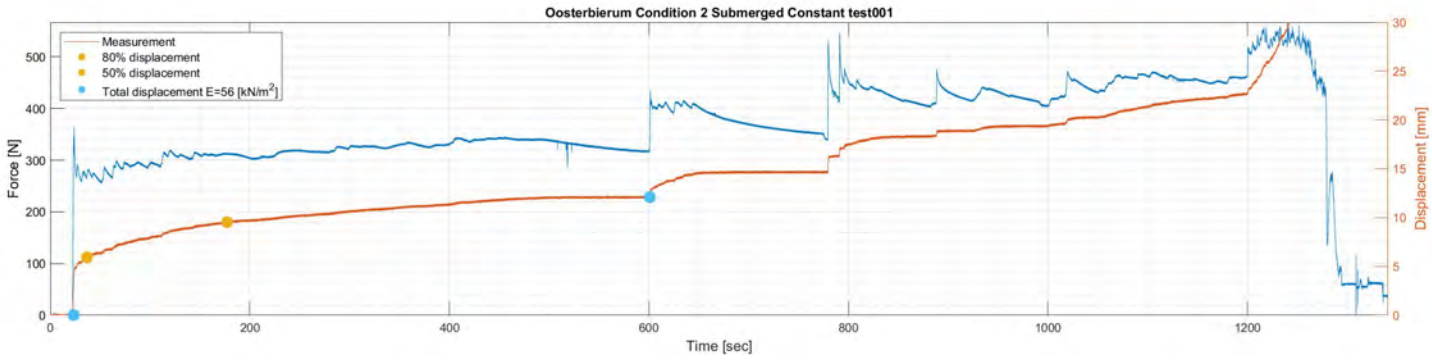
		value 1	value 2	value 3	mean
Date		12-3-2019			
E	$[kN/m^2]$	55.58			
Time to reach 80% of displacement	$[sec]$	155			
Width Sod	$[cm]$	25			
Weight Sod	$[N]$	59			
Sod Height	$[cm]$	13	9	4	10.5
Root Length	$[cm]$	4	4	4	4
Comments					

Figure 2.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

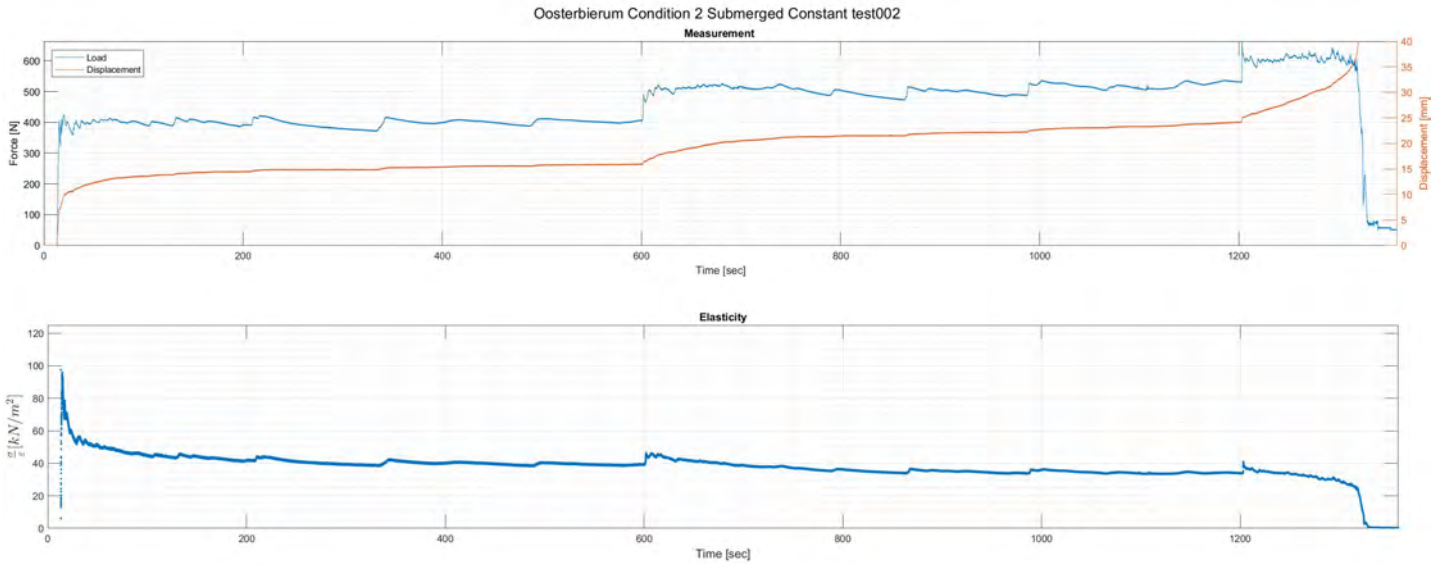




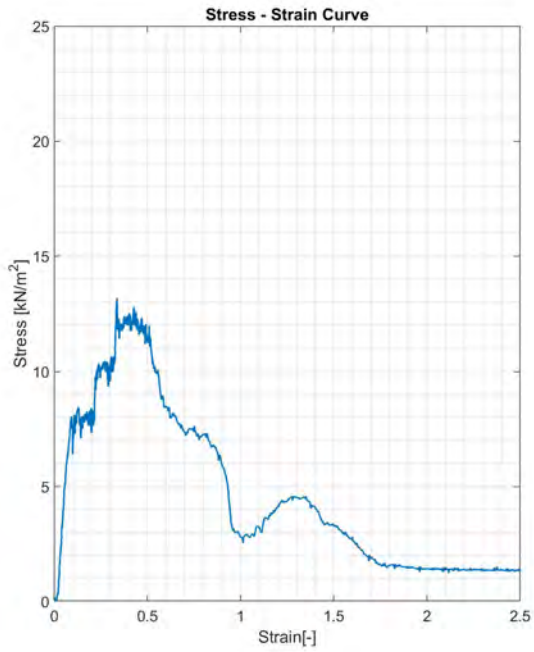
Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

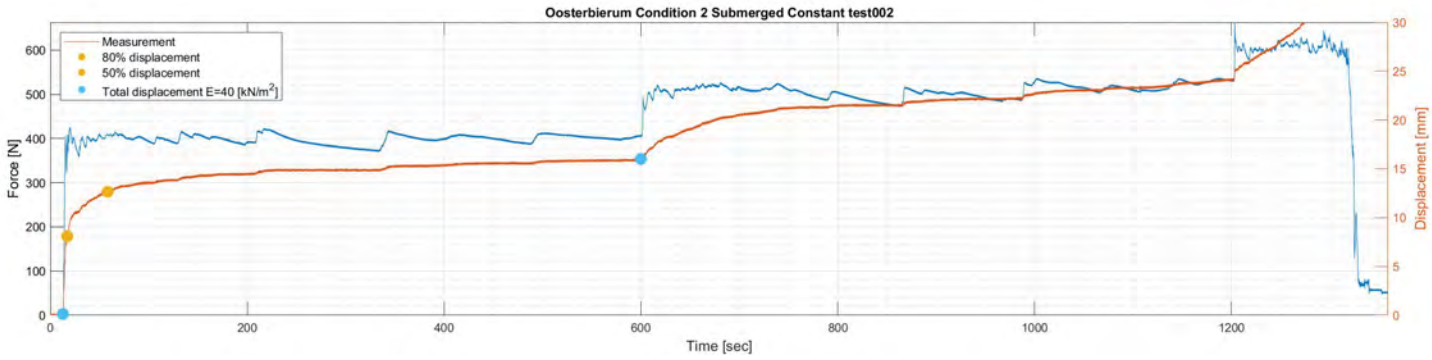
test002

		value 1	value 2	value 3	mean
Date		12-3-2019			
E	$[kN/m^2]$	39.36			
Time to reach 80% of displacement	$[sec]$	44			
Width Sod	$[cm]$	24			
Weight Sod	$[N]$	57			
Sod Height	$[cm]$	13	12	4	7.4
Root Length	$[cm]$	4	4	4	4
Comments					



Measurement of load and displacement and resulting elasticity.

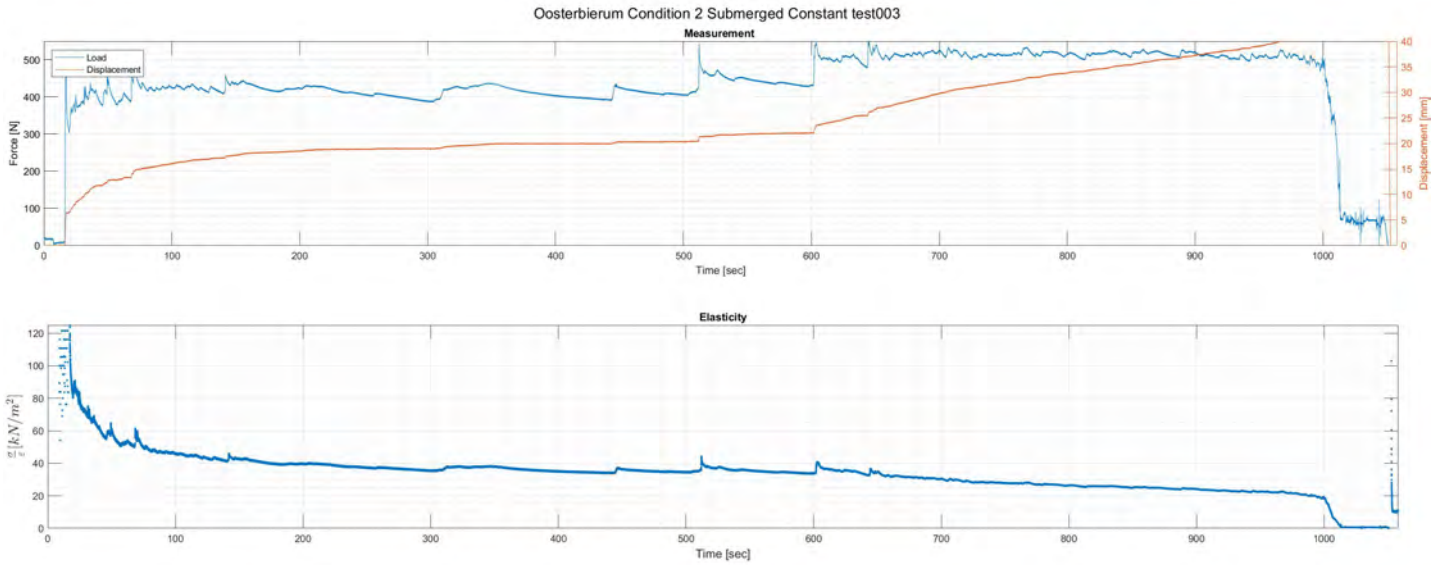




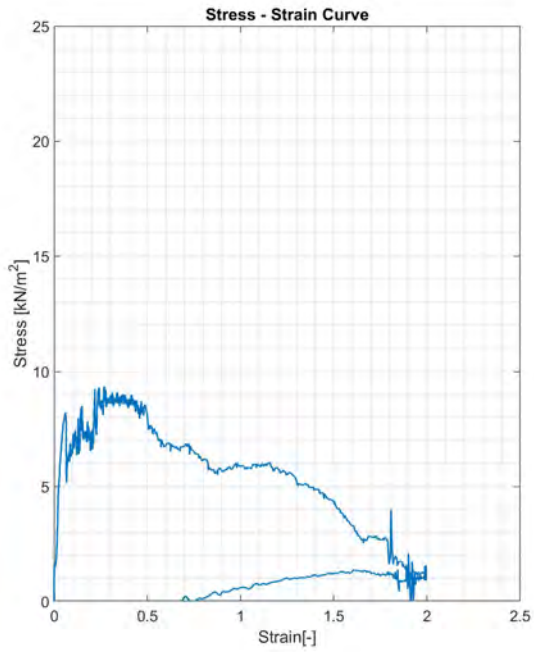
Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

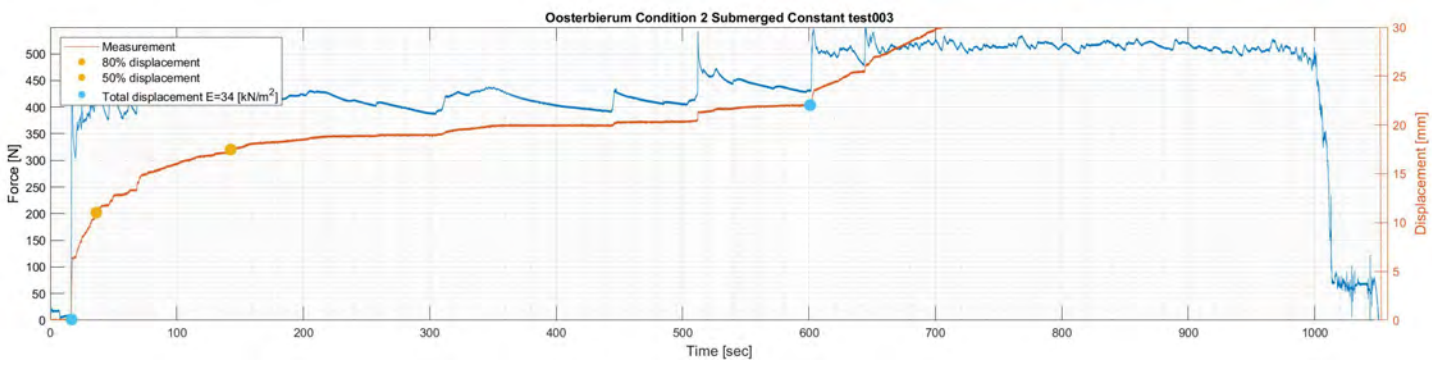
test003

		value 1	value 2	value 3	mean
Date		12-3-2019			
E	$[kN/m^2]$	33.87			
Time to reach 80% of displacement	$[sec]$	126			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	70			
Sod Height	$[cm]$	13	10	4	9.7
Root Length	$[cm]$	5	4	4	4.3
Comments					



Measurement of load and displacement and resulting elasticity.



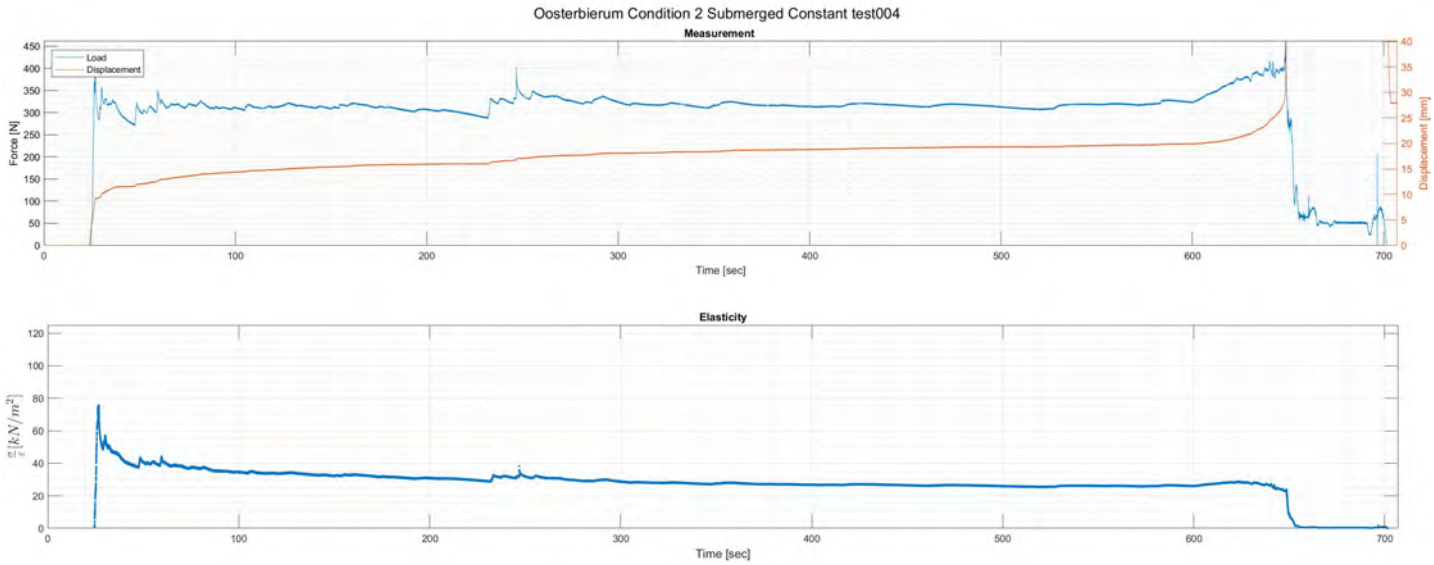


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

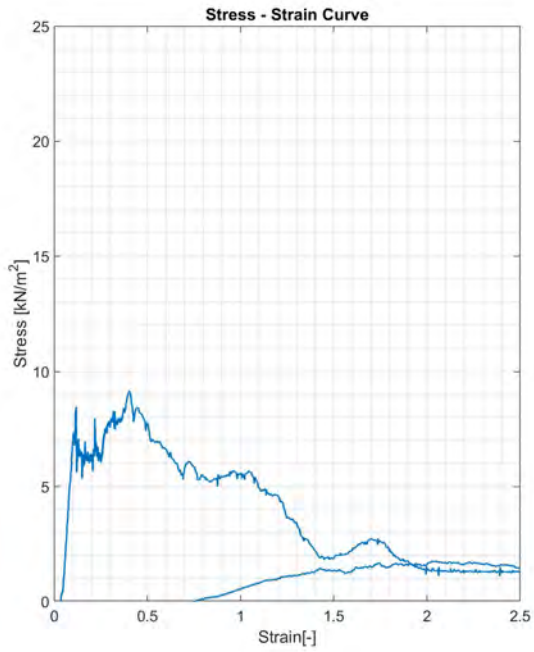
test004

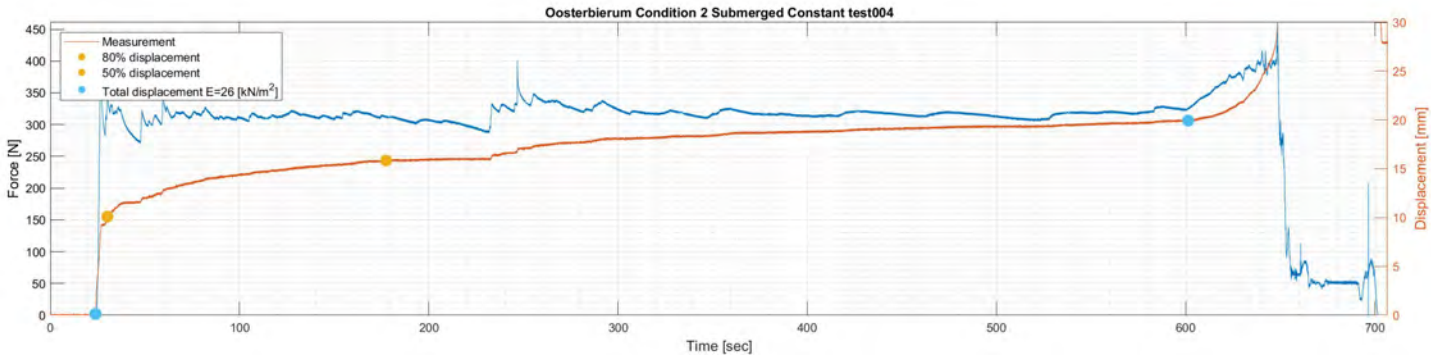
		value 1	value 2	value 3	mean
Date		14-3-2019			
E	$[kN/m^2]$	26.25			
Time to reach 80% of displacement	$[sec]$	153			
Width Sod	$[cm]$	24			
Weight Sod	$[N]$	24			
Sod Height	$[cm]$	11	8	5	7.7
Root Length	$[cm]$	3	5	5	4.6
Comments					

Figure 2.2: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



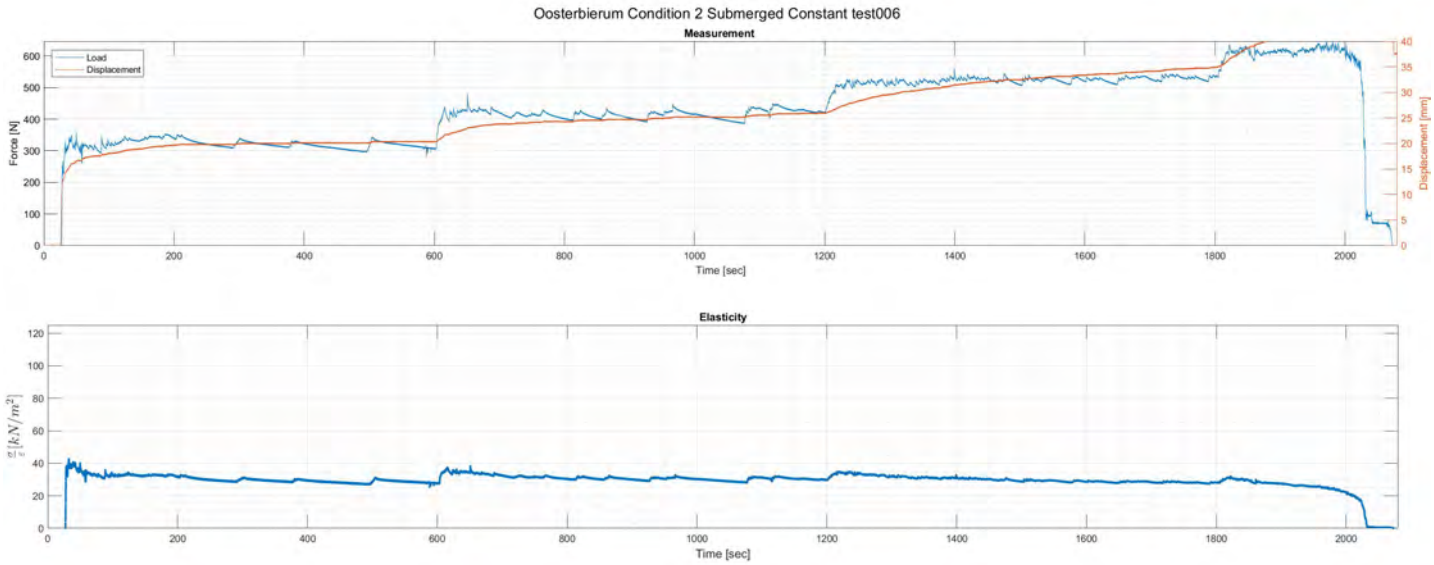


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

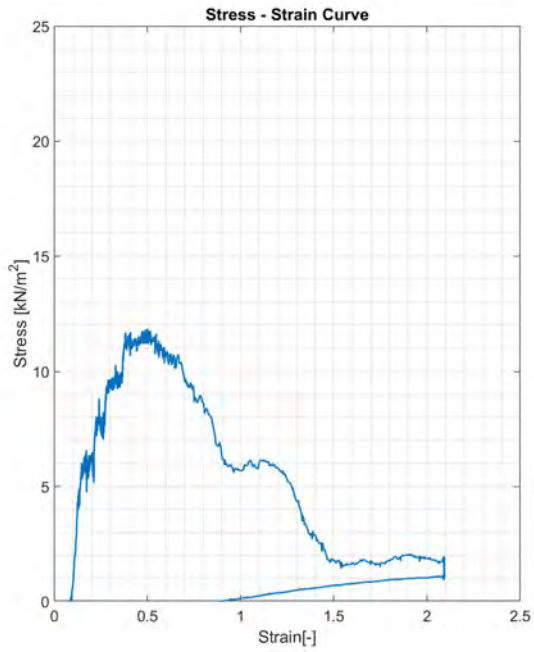
test006

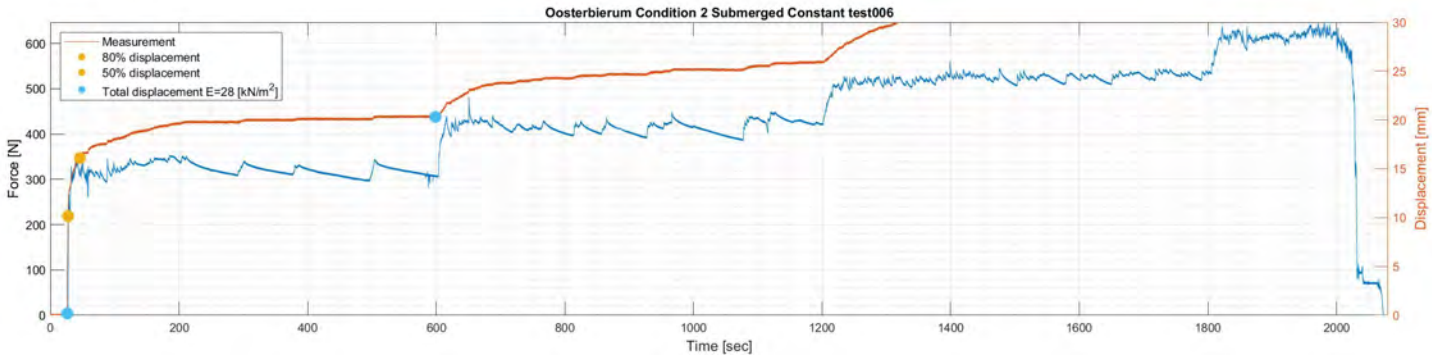
		value 1	value 2	value 3	mean
Date		18-3-2019			
E	$[kN/m^2]$	27.76			
Time to reach 80% of displacement	$[sec]$	19			
Width Sod	$[cm]$	26			
Weight Sod	$[N]$	69			
Sod Height	$[cm]$	13.5	10	5	9.6
Root Length	$[cm]$	1	2	5	2.6
Comments					

Figure 2.3: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



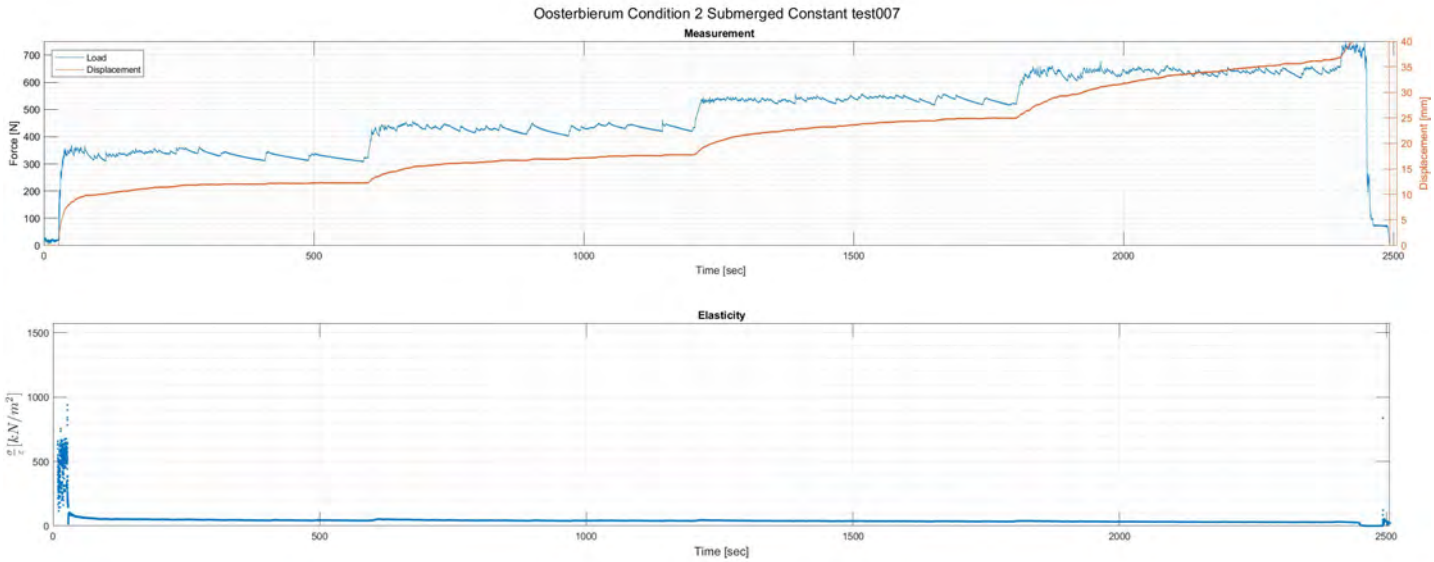


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

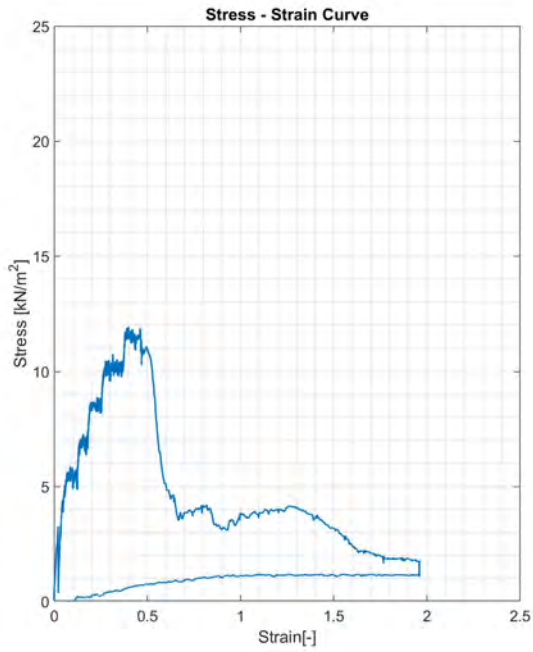
test007

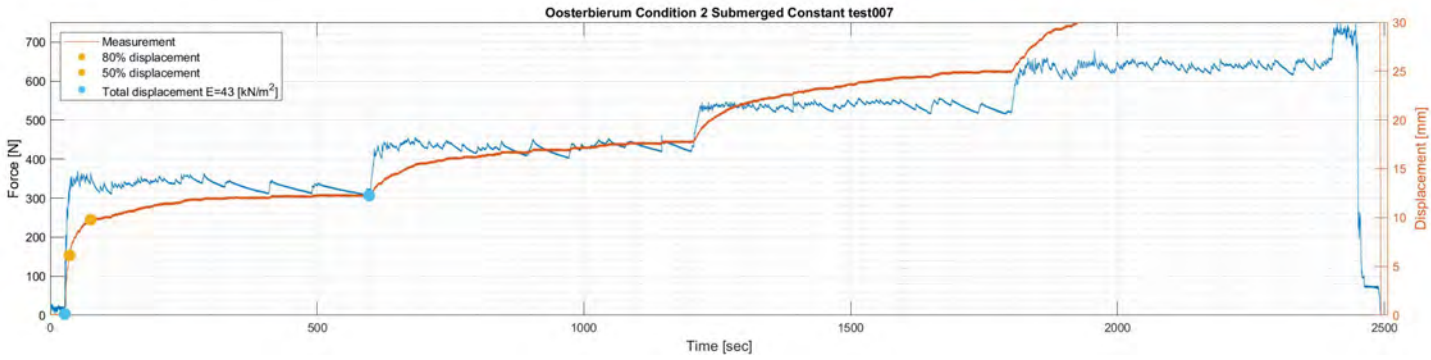
		value 1	value 2	value 3	mean
Date		18-3-2019			
E	$[kN/m^2]$	43.37			
Time to reach 80% of displacement	$[sec]$	73			
Width Sod	$[cm]$	30			
Weight Sod	$[N]$	74			
Sod Height	$[cm]$	13.5	10	8	9.9
Root Length	$[cm]$	4	8	8	6.8
Comments					

Figure 2.4: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



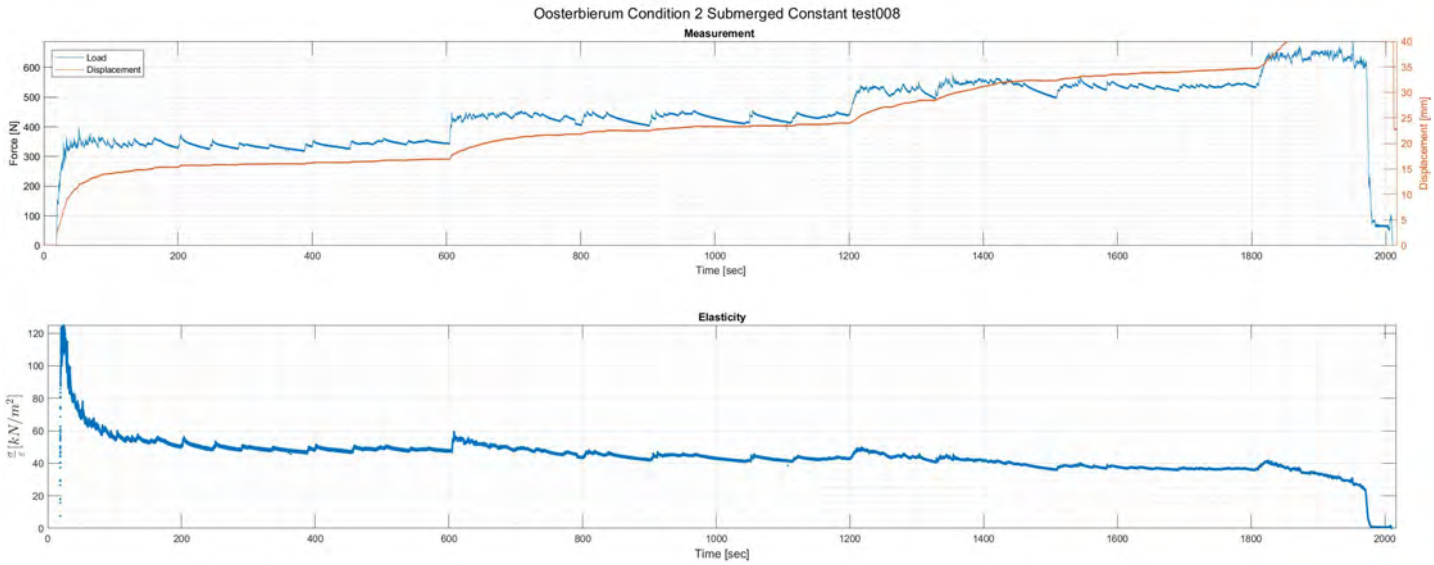


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

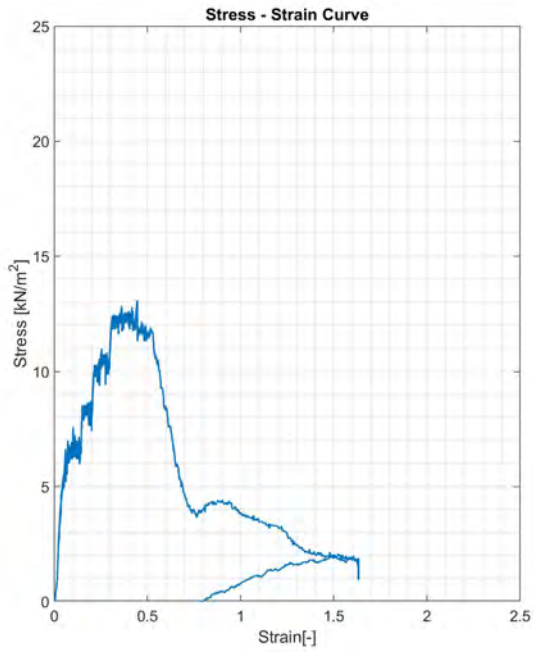
test008

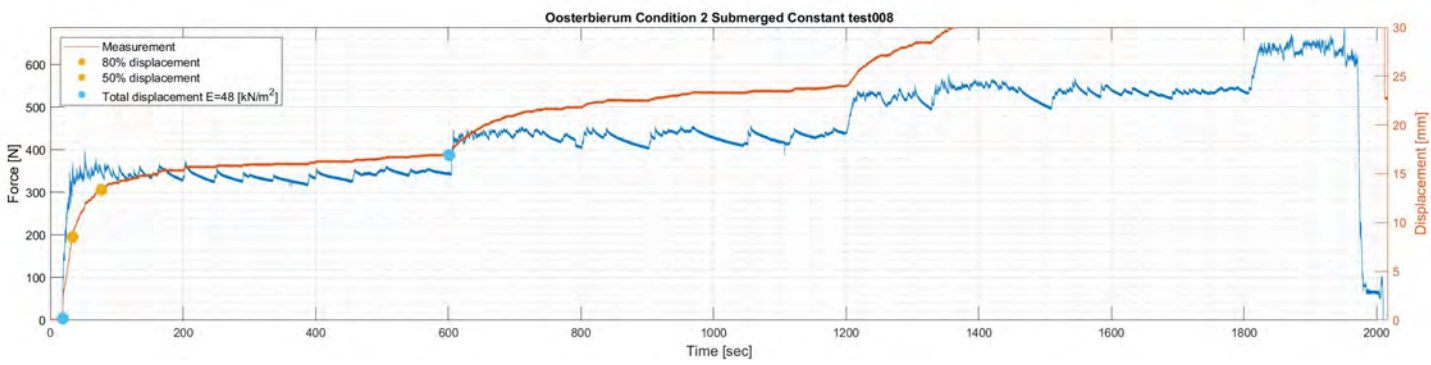
		value 1	value 2	value 3	mean
Date		18-3-2019			
E	$[kN/m^2]$	47.7			
Time to reach 80% of displacement	$[sec]$	58			
Width Sod	$[cm]$	25			
Weight Sod	$[N]$	64			
Sod Height	$[cm]$	13.5	8	10	11.7
Root Length	$[cm]$	6	10	10	7.6
Comments					

Figure 2.5: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.





Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

Submerged Condition 2 Cyclic

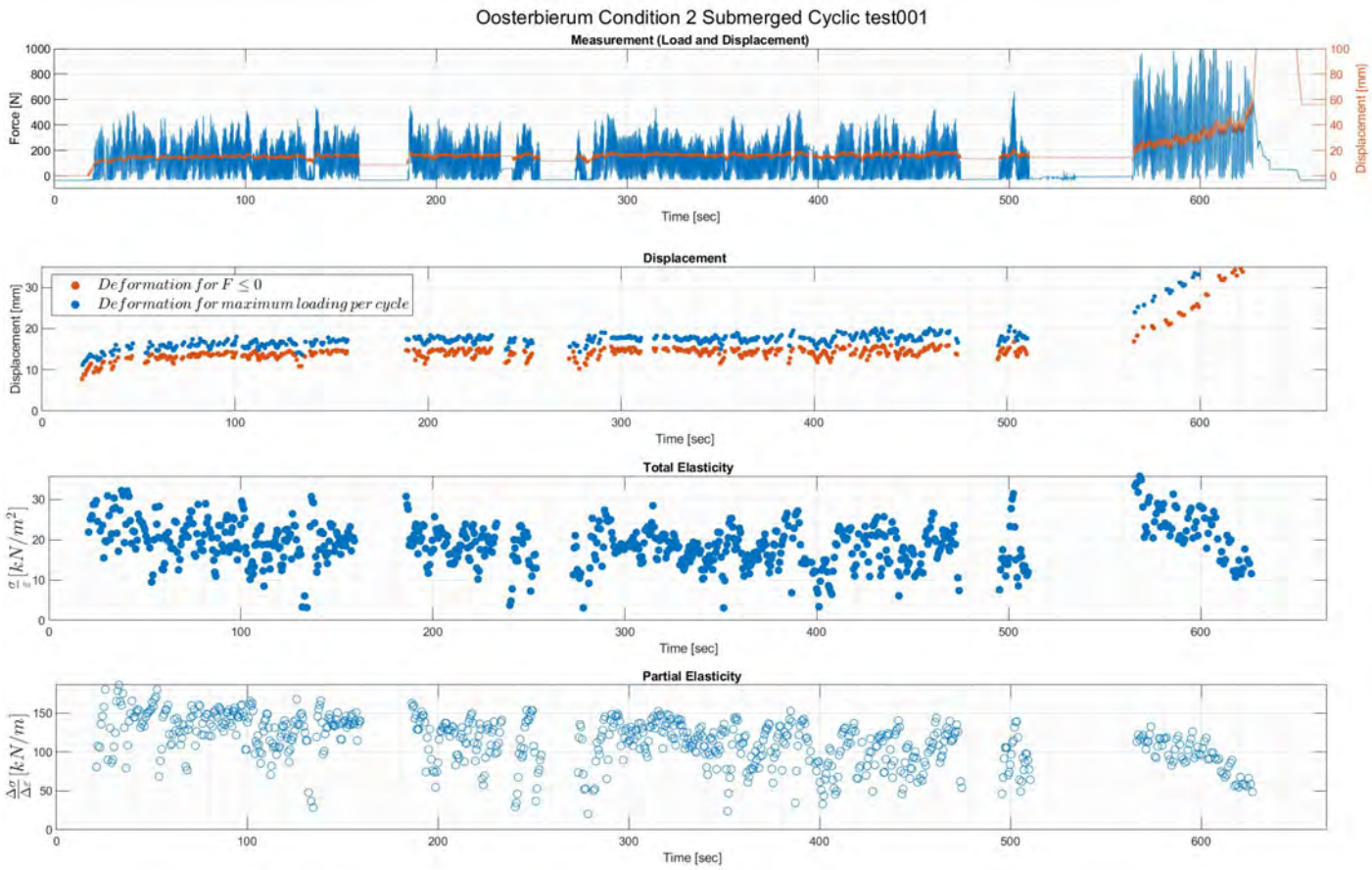
	Growth rate $\frac{\Delta U}{n}$ $[mm]$						Load					
	Plastic deformation			Maximum deformation			Mean			Mean maximum		
Load block	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800
test001	3.08e-03	2.88e-01	NaN	4.62e-03	3.35e-01	NaN	1.48e+02	3.81e+02	NaN	3.08e+02	7.29e+02	NaN
test002	4.81e-03	7.31e-02	NaN	4.94e-03	1.38e-01	NaN	1.85e+02	3.63e+02	NaN	3.80e+02	7.19e+02	NaN
test003	1.82e-03	2.32e-02	NaN	2.45e-03	2.91e-02	NaN	1.71e+02	3.57e+02	NaN	3.53e+02	7.19e+02	NaN
test004	1.94e-03	3.94e-02	NaN	2.35e-03	5.95e-02	NaN	1.56e+02	3.18e+02	NaN	3.16e+02	6.31e+02	NaN
test005	2.09e-03	8.33e-02	NaN	4.21e-03	1.50e-01	NaN	1.35e+02	3.29e+02	NaN	2.80e+02	6.66e+02	NaN
test006	-1.05e-03	1.81e-02	NaN	-2.28e-04	2.68e-02	NaN	8.90e+01	2.78e+02	NaN	1.88e+02	5.62e+02	NaN
mean	2.11e-03	8.75e-02	NaN	3.06e-03	1.23e-01	NaN	1.47e+02	3.37e+02	NaN	3.04e+02	6.71e+02	NaN
median	2.01e-03	5.63e-02	NaN	3.33e-03	9.86e-02	NaN	1.52e+02	3.43e+02	NaN	3.12e+02	6.92e+02	NaN
75th percentile	3.08e-03	8.33e-02	NaN	4.62e-03	1.50e-01	NaN	1.71e+02	3.63e+02	NaN	3.53e+02	7.19e+02	NaN
25th percentile	1.82e-03	2.32e-02	NaN	2.35e-03	2.91e-02	NaN	1.35e+02	3.18e+02	NaN	2.80e+02	6.31e+02	NaN

	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test001	4.8	38.0	8.4	7.6
test002	5.3	32.0	7.0	6.1
test003	6.6	34.0	9.0	10.0
test004	6.1	30.0	9.5	7.4
test005	NaN	30.0	8.6	5.8
test006	5.3	25.0	9.2	6.2
Mean	5.6	31.5	8.6	7.2
Median	5.3	31	8.8	6.8
75th percentile	6.2	34	9.2	7.6
25th percentile	5.2	34	8.4	6.1

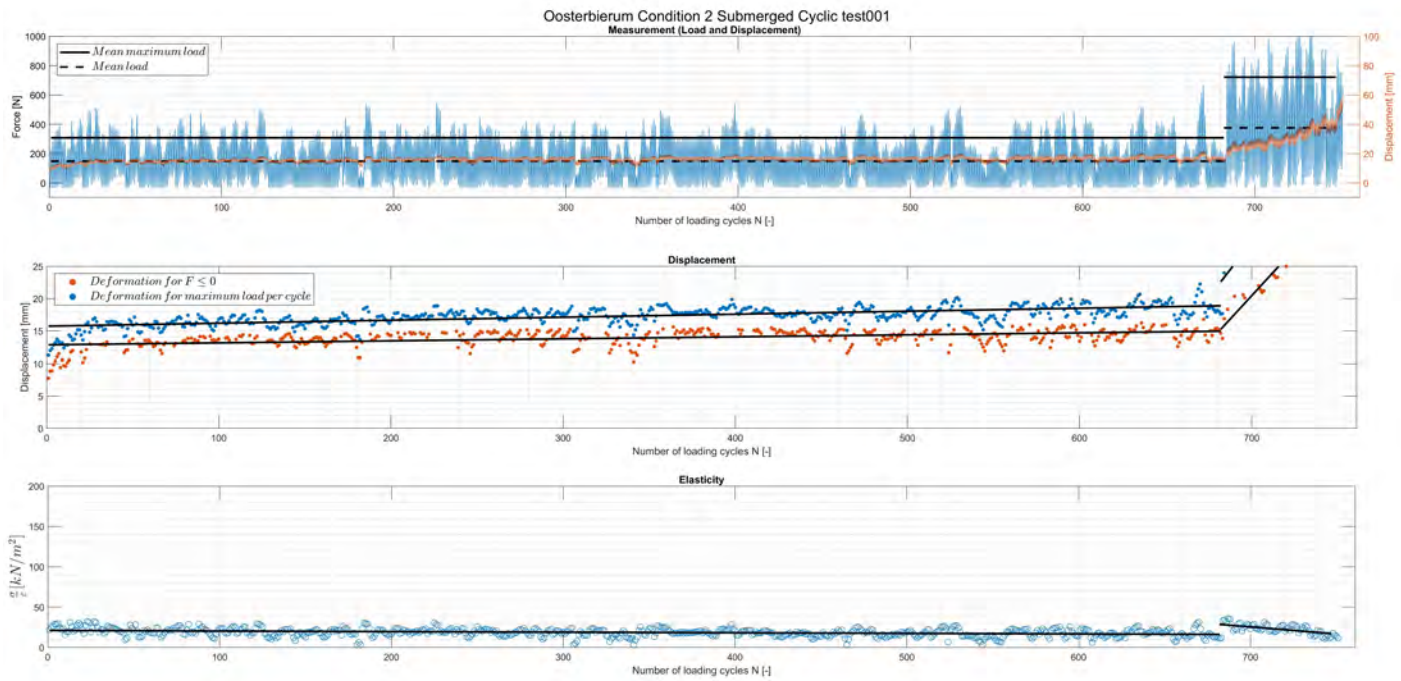
test001

		value 1	value 2	value 3	mean
Date		15-4-2019			
Mean load	$[N]$	1.48e+02	3.81e+02		2.64e+02
Mean maximum load	$[N]$	3.08e+02	7.29e+02		5.19e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	3.08e-03	2.88e-01		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	4.62e-03	3.35e-01		
Width Sod	$[cm]$	38			
Weight Sod	$[N]$	48			
Sod Height	$[cm]$	10	8	8	8.4
Root Length	$[cm]$	6	8	8	7.6
Comments					

Figure 3.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

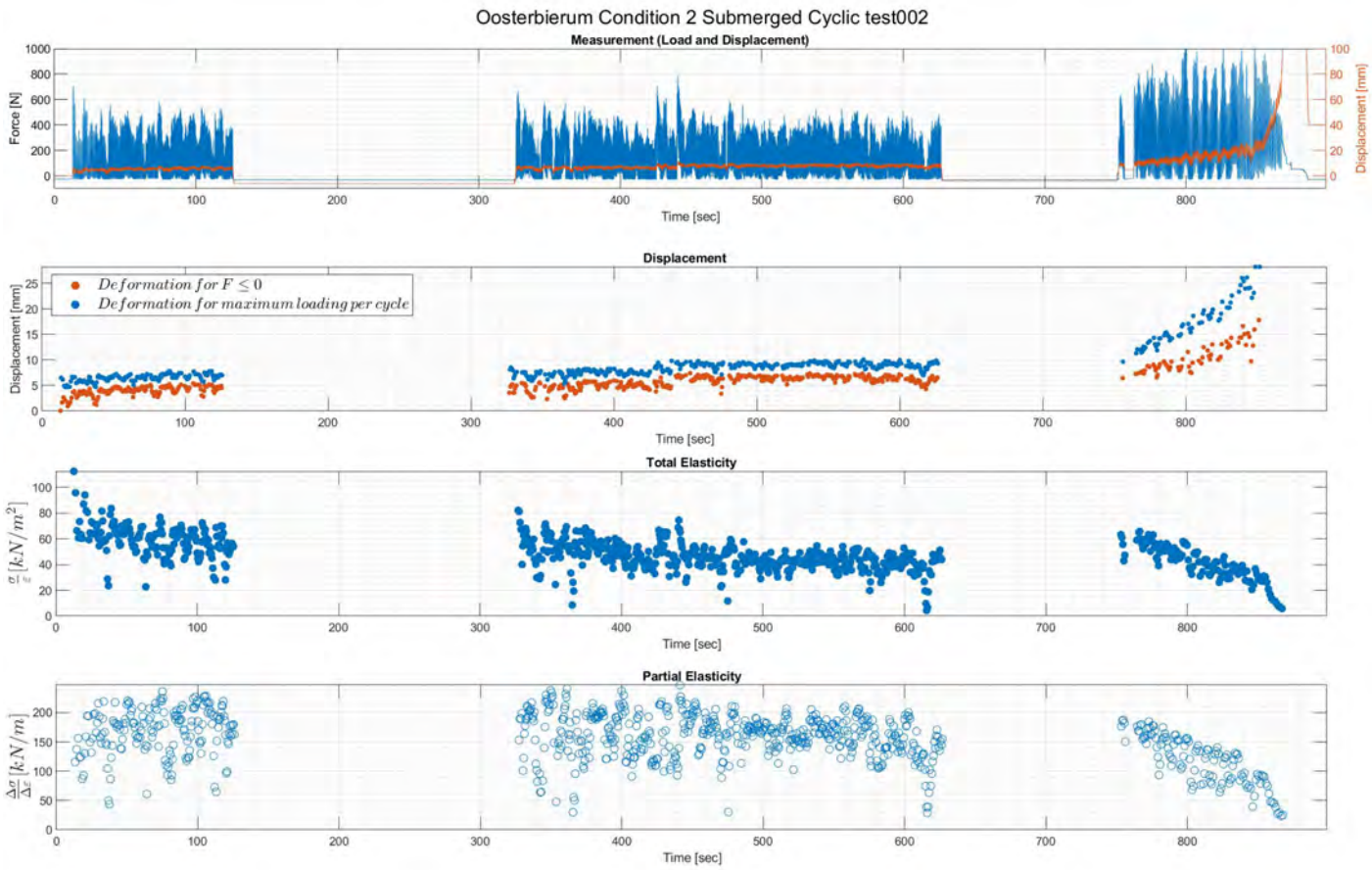


Development of displacement and elasticity are shown as function of number of cycles.

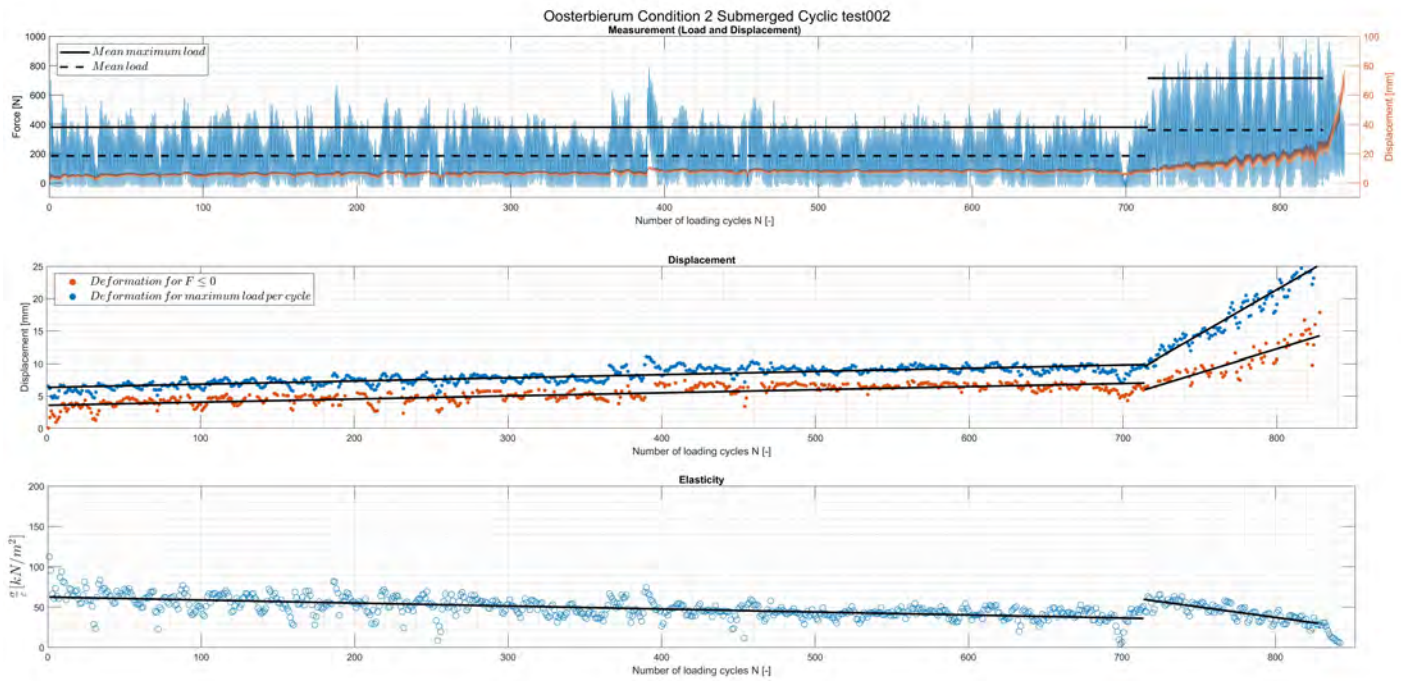
test002

		value 1	value 2	value 3	mean
Date		15-4-2019			
Mean load	$[N]$	1.85e+02	3.63e+02		2.74e+02
Mean maximum load	$[N]$	3.80e+02	7.19e+02		5.49e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	4.81e-03	7.31e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	4.94e-03	1.38e-01		
Width Sod	$[cm]$	32			
Weight Sod	$[N]$	53			
Sod Height	$[cm]$	8	6	8	7
Root Length	$[cm]$	5	6	8	6.1
Comments					

Figure 3.2: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

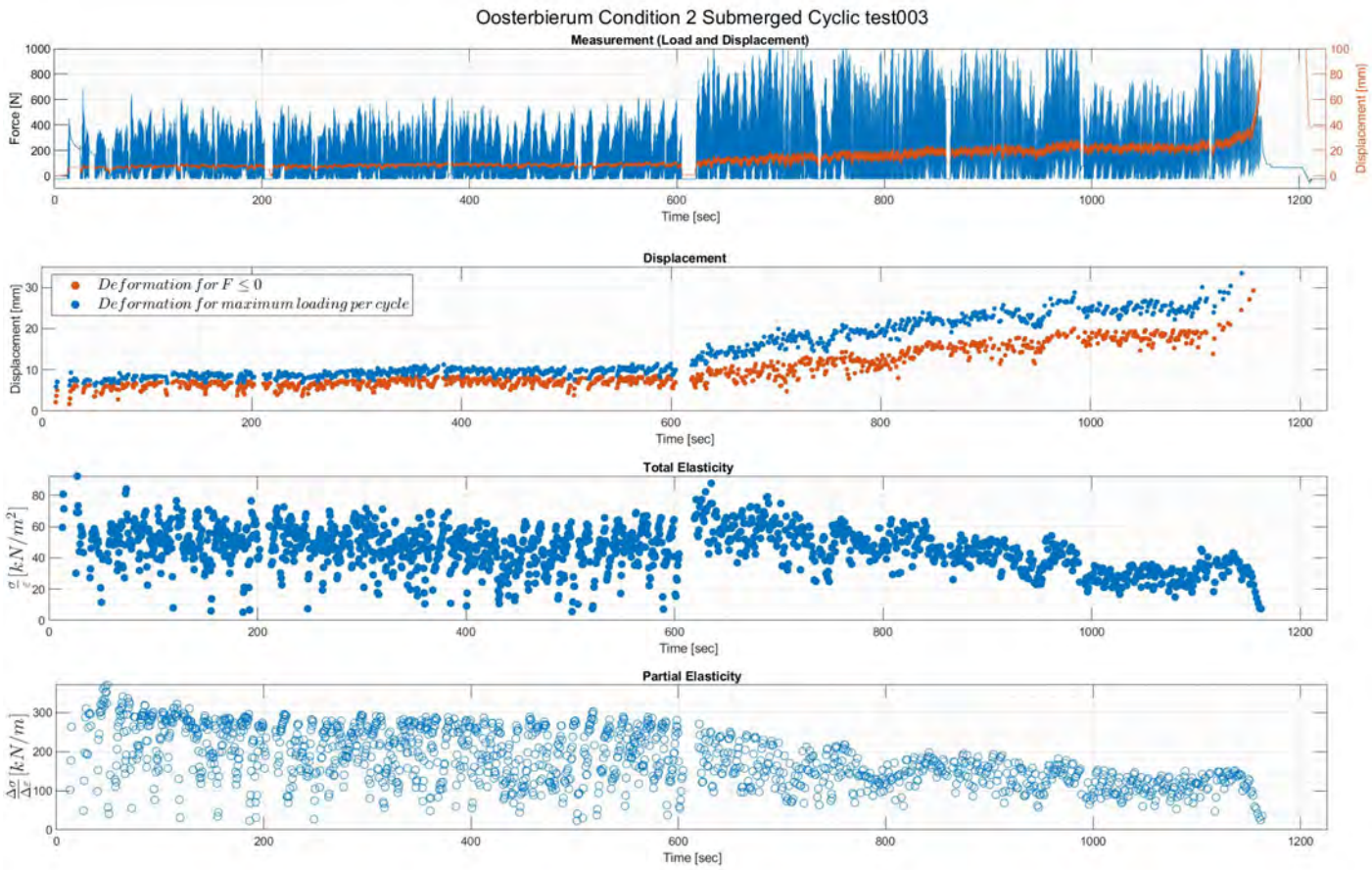


Development of displacement and elasticity are shown as function of number of cycles.

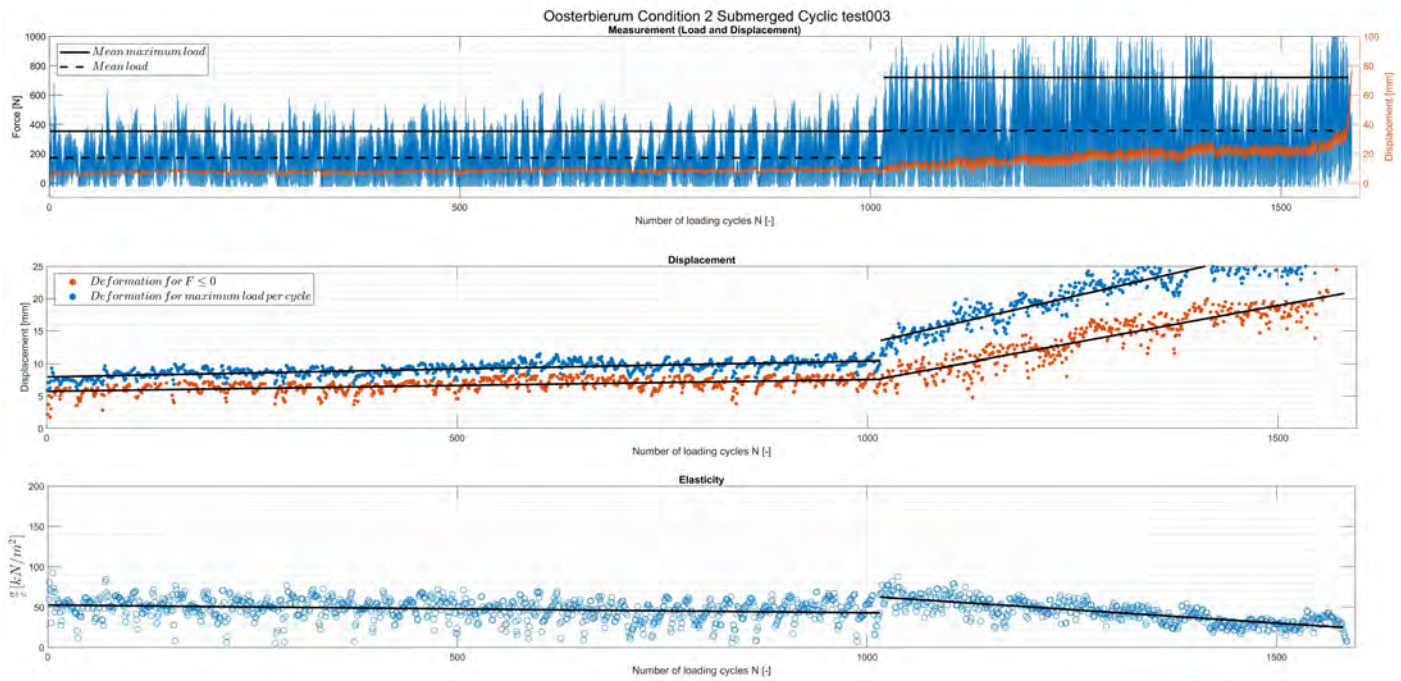
test003

		value 1	value 2	value 3	mean
Date		15-4-2019			
Mean load	$[N]$	1.71e+02	3.57e+02		2.64e+02
Mean maximum load	$[N]$	3.53e+02	7.19e+02		5.36e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	1.82e-03	2.32e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	2.45e-03	2.91e-02		
Width Sod	$[cm]$	34			
Weight Sod	$[N]$	66			
Sod Height	$[cm]$	10	8	10	9
Root Length	$[cm]$	10	10	10	10
Comments		gesneden door bak			

Figure 3.3: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

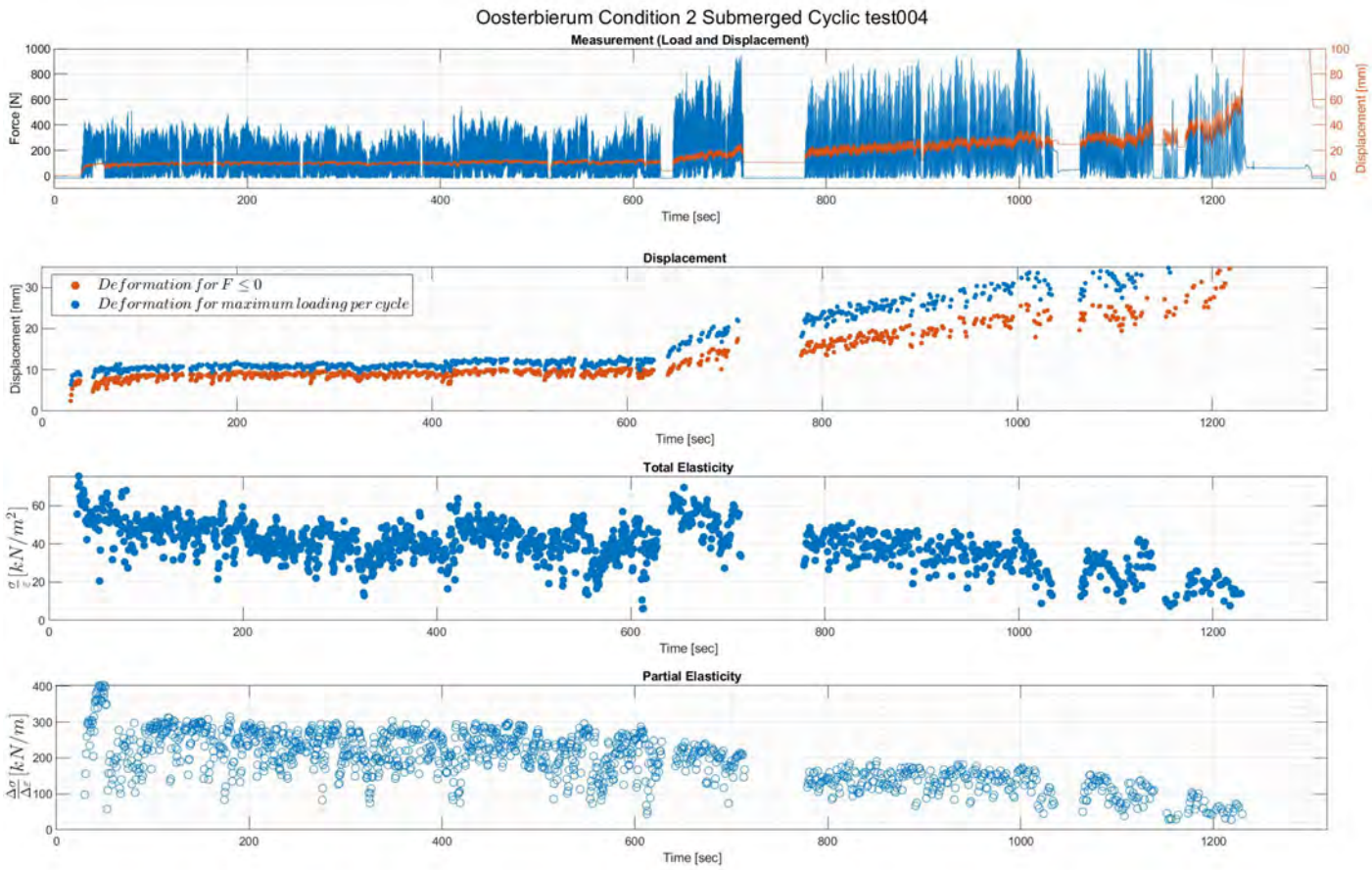


Development of displacement and elasticity are shown as function of number of cycles.

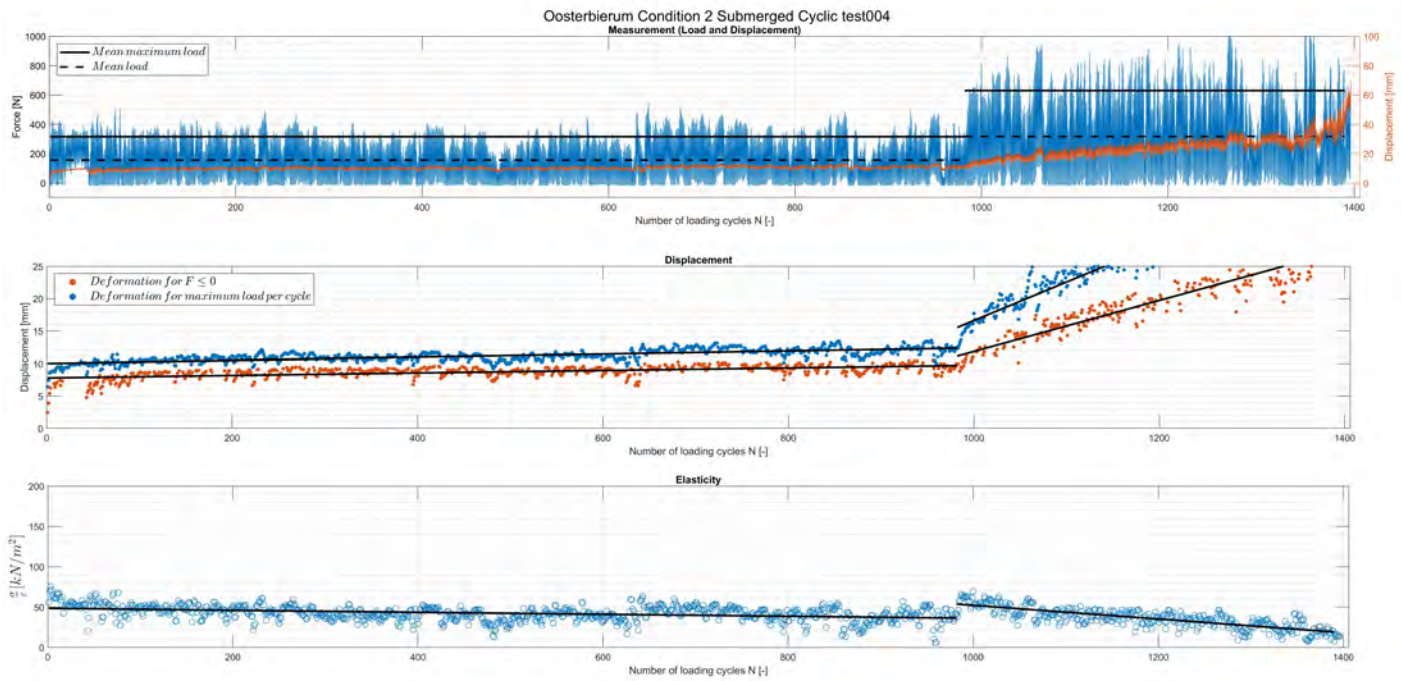
test004

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	1.56e+02	3.18e+02		2.37e+02
Mean maximum load	$[N]$	3.16e+02	6.31e+02		4.73e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	1.94e-03	3.94e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	2.35e-03	5.95e-02		
Width Sod	$[cm]$	30			
Weight Sod	$[N]$	61			
Sod Height	$[cm]$	11	9	8	9.5
Root Length	$[cm]$	6	8	8	7.4
Comments		gesneden door bak			

Figure 3.4: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

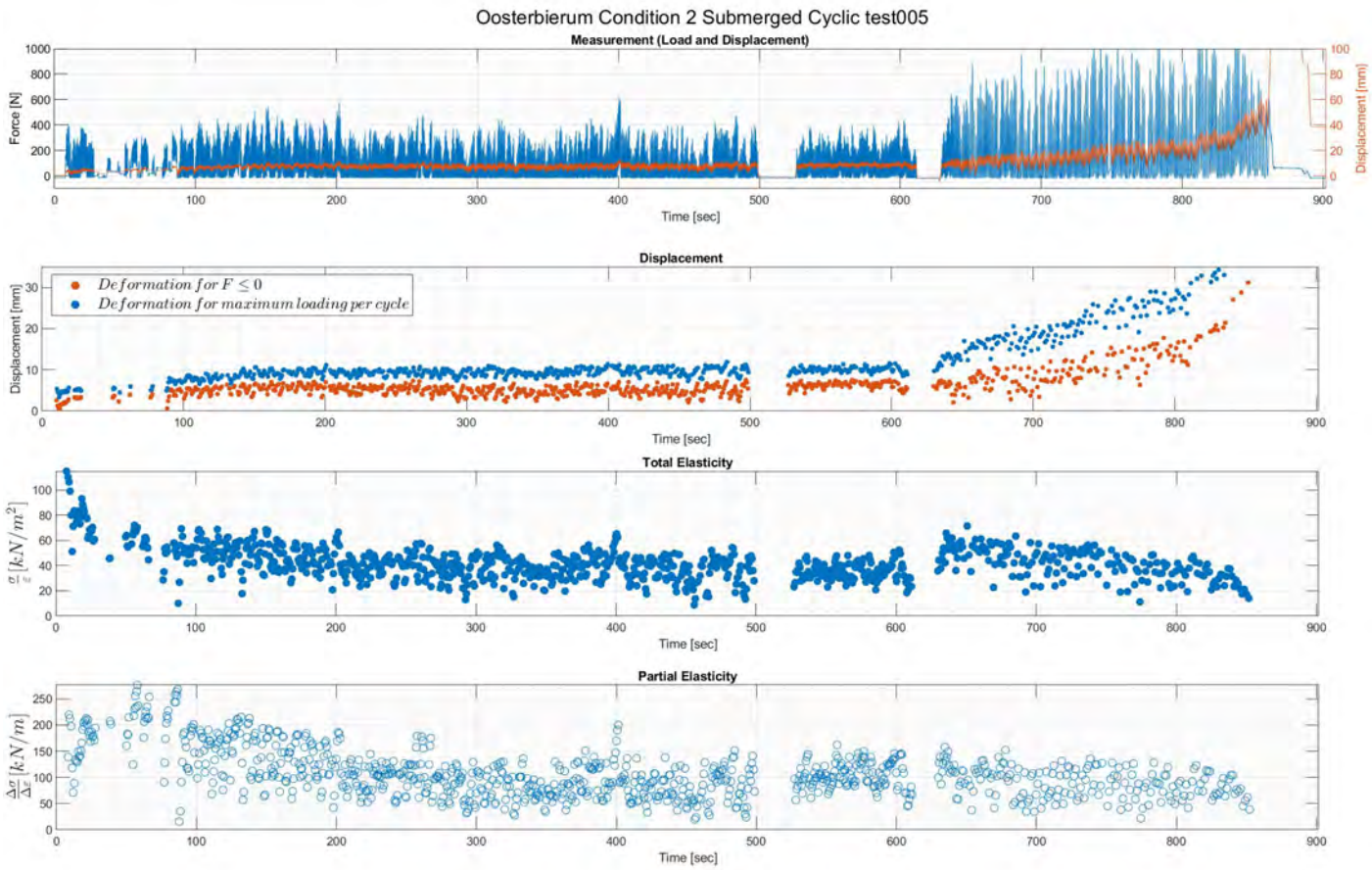


Development of displacement and elasticity are shown as function of number of cycles.

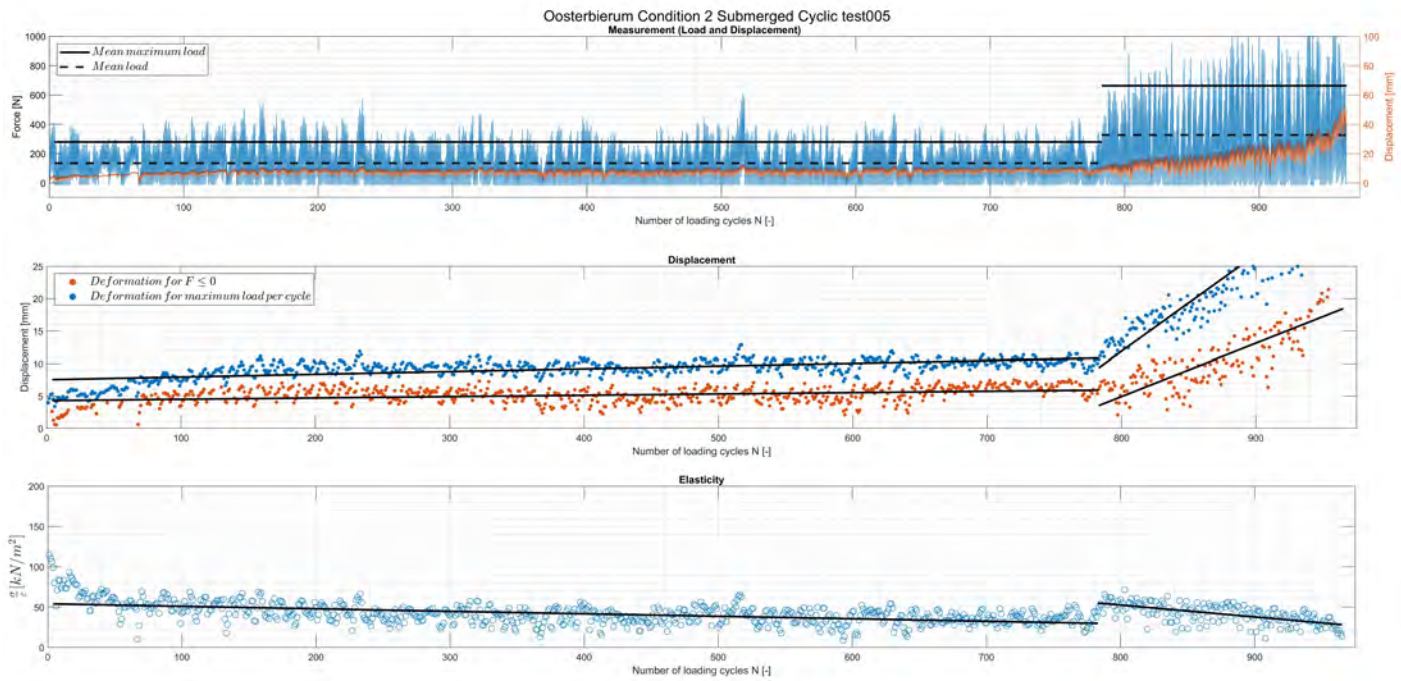
test005

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	1.35e+02	3.29e+02		2.32e+02
Mean maximum load	$[N]$	2.80e+02	6.66e+02		4.73e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	2.09e-03	8.33e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	4.21e-03	1.50e-01		
Width Sod	$[cm]$	30			
Weight Sod	$[N]$	NaN			
Sod Height	$[cm]$	10	8	7	8.6
Root Length	$[cm]$	4	7	7	5.8
Comments					

Figure 3.5: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

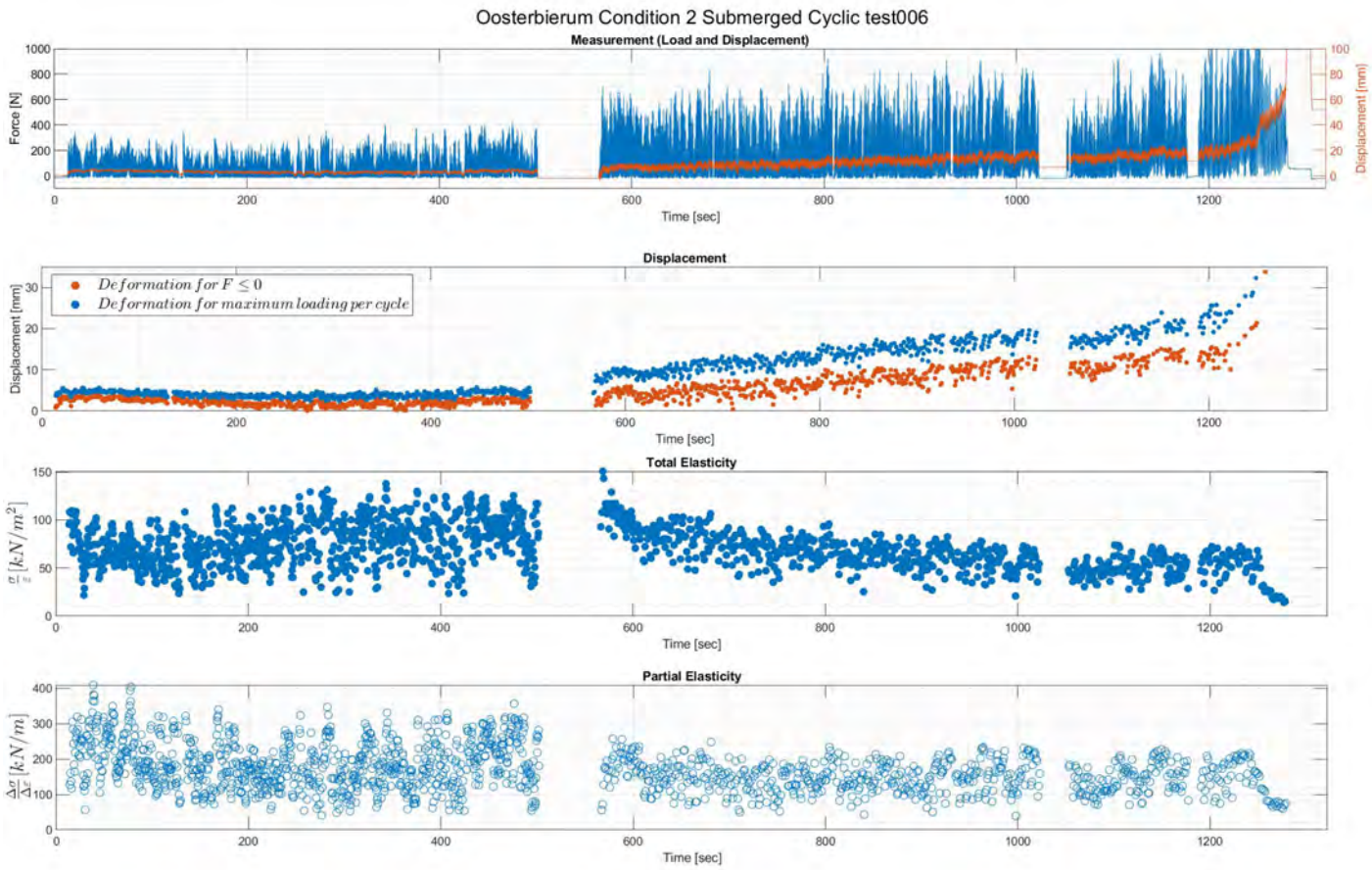


Development of displacement and elasticity are shown as function of number of cycles.

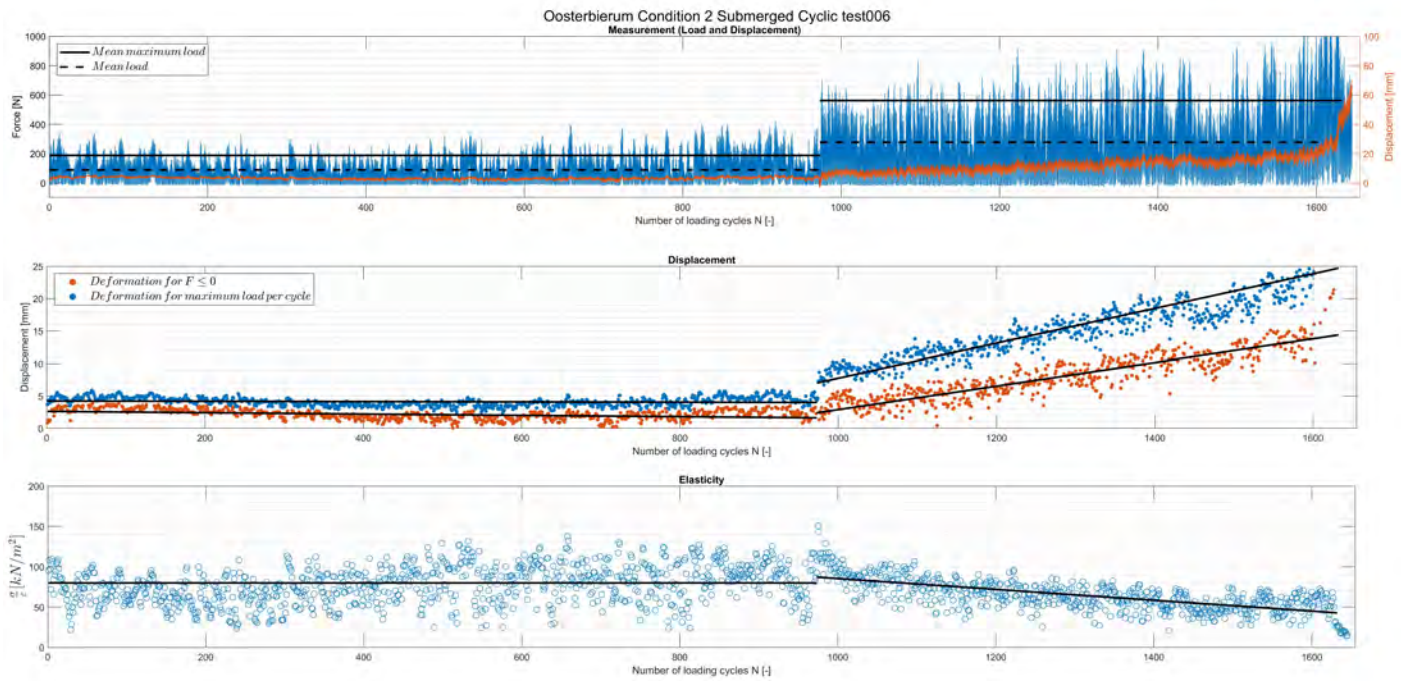
test006

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	8.90e+01	2.78e+02		1.84e+02
Mean maximum load	$[N]$	1.88e+02	5.62e+02		3.75e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	-1.05e-03	1.81e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	-2.28e-04	2.68e-02		
Width Sod	$[cm]$	25			
Weight Sod	$[N]$	53			
Sod Height	$[cm]$	12	8	8	9.2
Root Length	$[cm]$	4	7	8	6.2
Comments		Perfecte breedte			

Figure 3.6: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



Development of displacement and elasticity are shown as function of number of cycles.

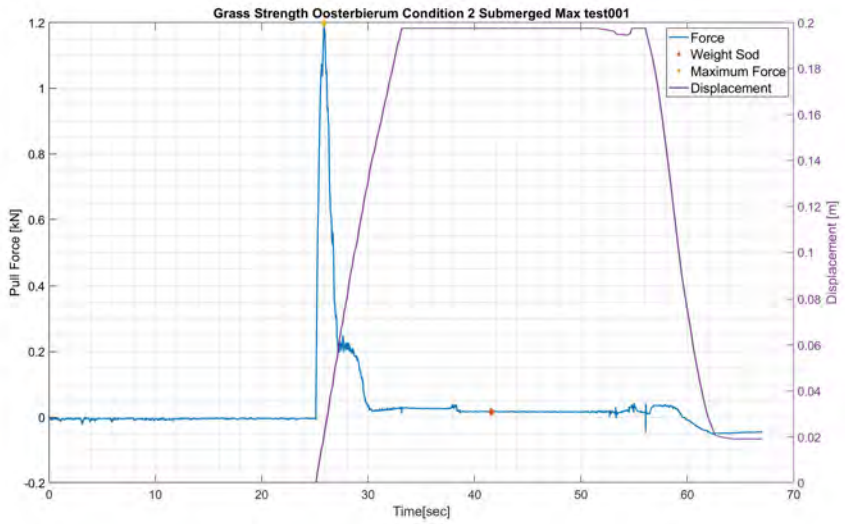
Submerged Condition 2 Max

	F max $[N]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test001	1185	1.5	24	6.6	5.0
test002	1225	3.0	25	6.6	3.4
test003	1118	3.6	24	7.4	3.0
test004	1509	3.5	24	6.7	5.6
test005	1321	2.9	24	7.5	6.9
test006	1145	3.7	30	5.0	9.0
test007	1261	2.4	26	6.8	7.1
test008	1188	3.0	28	7.2	7.0
test009	1188	5.2	28	8.4	7.6
test4002	908	4.8	29	8.0	6.0
Mean	1202	3.4	26.2	7	6.1
Median	1188	3.3	26	7	6
75th percentile	1261	3.7	28	8	7
25th percentile	1145	2.9	28	7	5

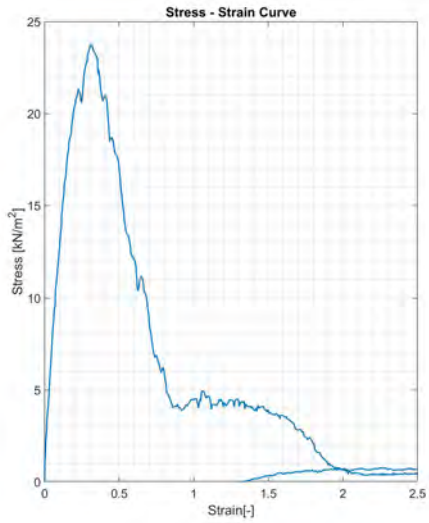
test001

		value 1	value 2	value 3	mean
Date		14-3-2019			
Maximum load	$[N]$	1185			
Width Sod	$[cm]$	24			
Weight Sod	$[N]$	15			
Sod Height	$[cm]$	9	6	0	6.6
Root Length	$[cm]$	5	5	0	5
Comments					

Figure 4.1: Pictures of tested grass sod.



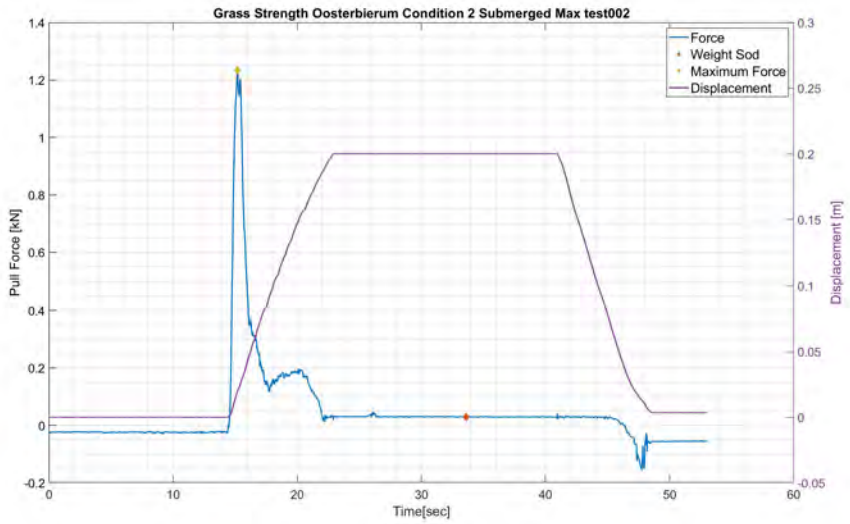
Measurement of load and displacement



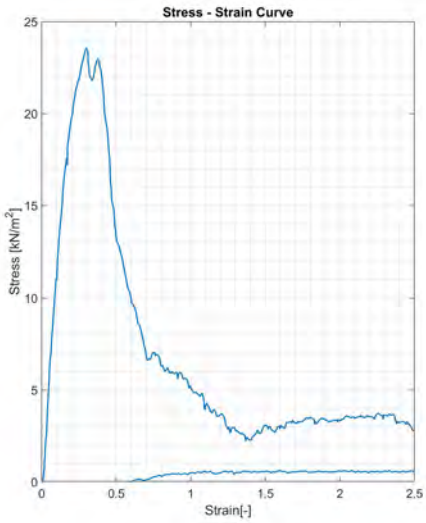
Stress - Strain relation.

test002

		value 1	value 2	value 3	mean
Date		14-3-2019			
Maximum load	$[N]$	1220			
Width Sod	$[cm]$	25			
Weight Sod	$[N]$	30			
Sod Height	$[cm]$	12	8	2	6.6
Root Length	$[cm]$	4	4	2	3.4
Comments					



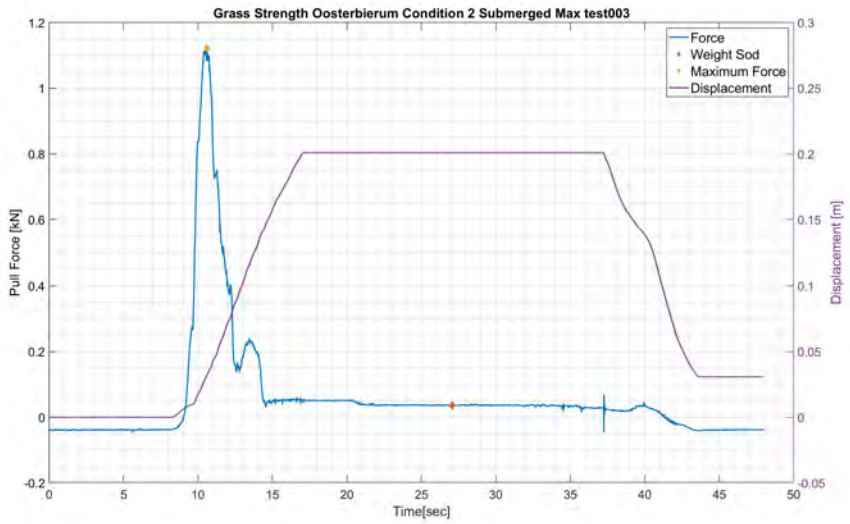
Measurement of load and displacement



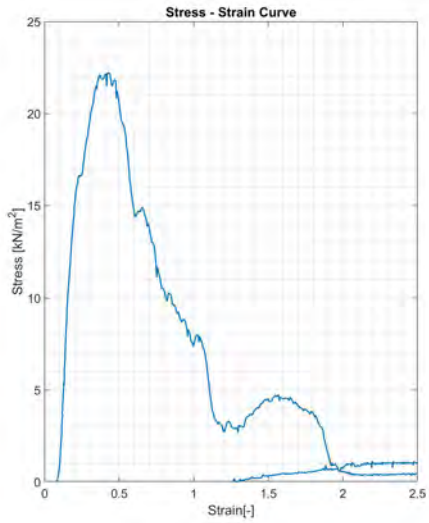
Stress - Strain relation.

test003

		value 1	value 2	value 3	mean
Date		14-3-2019			
Maximum load	$[N]$	1114			
Width Sod	$[cm]$	24			
Weight Sod	$[N]$	36			
Sod Height	$[cm]$	8	6	0	7.4
Root Length	$[cm]$	3	3	0	3
Comments					



Measurement of load and displacement

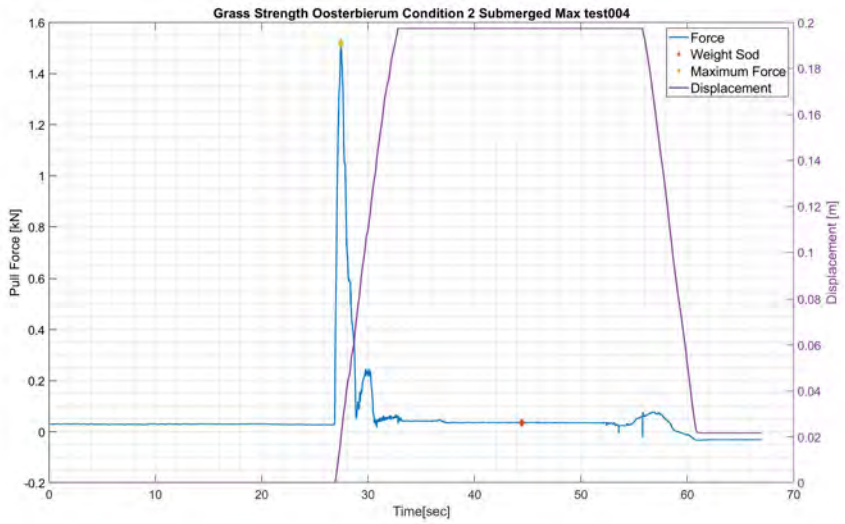


Stress - Strain relation.

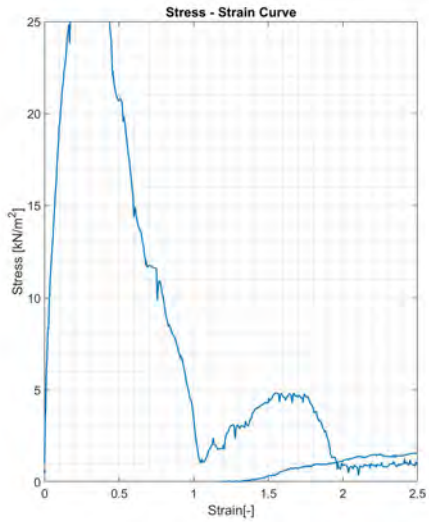
test004

		value 1	value 2	value 3	mean
Date		15-3-2019			
Maximum load	$[N]$	1502			
Width Sod	$[cm]$	24			
Weight Sod	$[N]$	35			
Sod Height	$[cm]$	10	7	6	6.7
Root Length	$[cm]$	2	6	6	5.6
Comments					

Figure 4.2: Pictures of tested grass sod.



Measurement of load and displacement

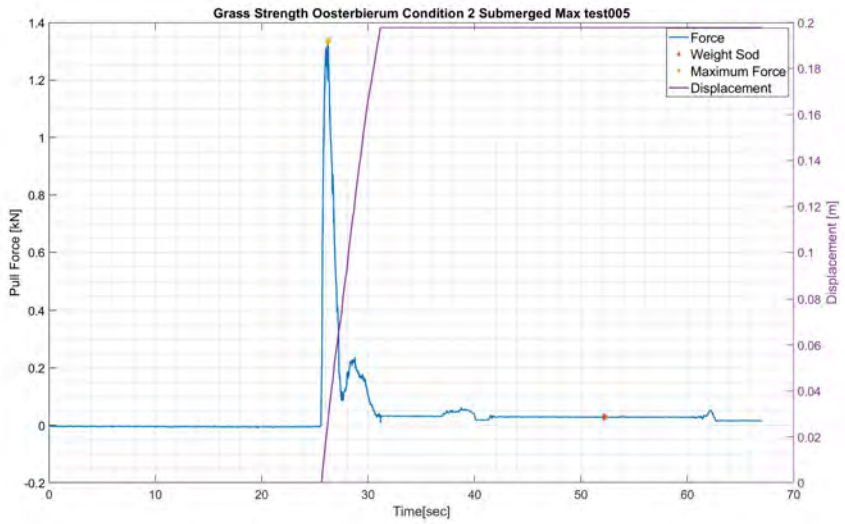


Stress - Strain relation.

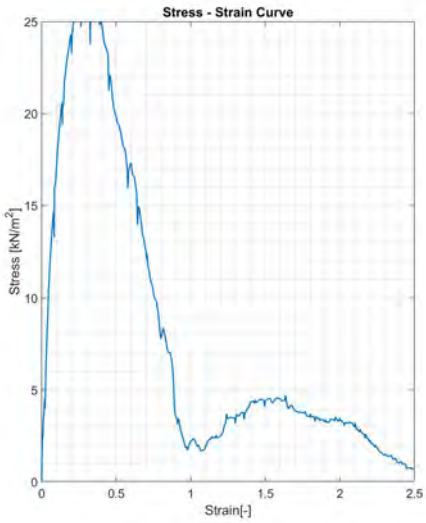
test005

		value 1	value 2	value 3	mean
Date		15-3-2019			
Maximum load	$[N]$	1312			
Width Sod	$[cm]$	24			
Weight Sod	$[N]$	29			
Sod Height	$[cm]$	11	8	7	7.5
Root Length	$[cm]$	6	7	7	6.9
Comments					

Figure 4.3: Pictures of tested grass sod.



Measurement of load and displacement

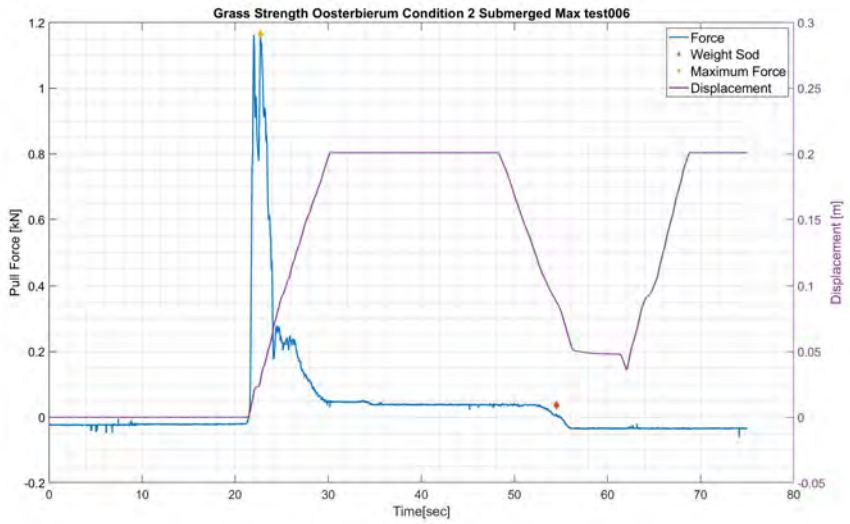


Stress - Strain relation.

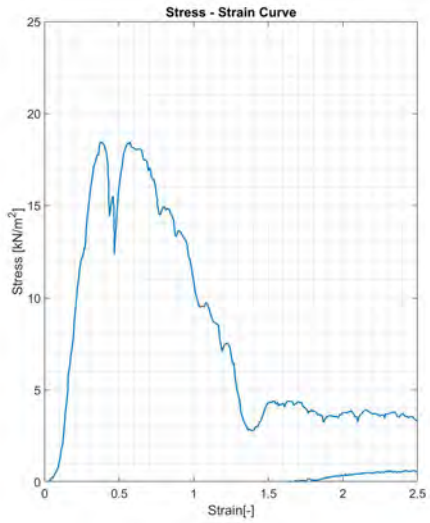
test006

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	1148			
Width Sod	$[cm]$	30			
Weight Sod	$[N]$	37			
Sod Height	$[cm]$	6	4	0	5
Root Length	$[cm]$	9	9	0	9
Comments					

Figure 4.4: Pictures of tested grass sod.



Measurement of load and displacement

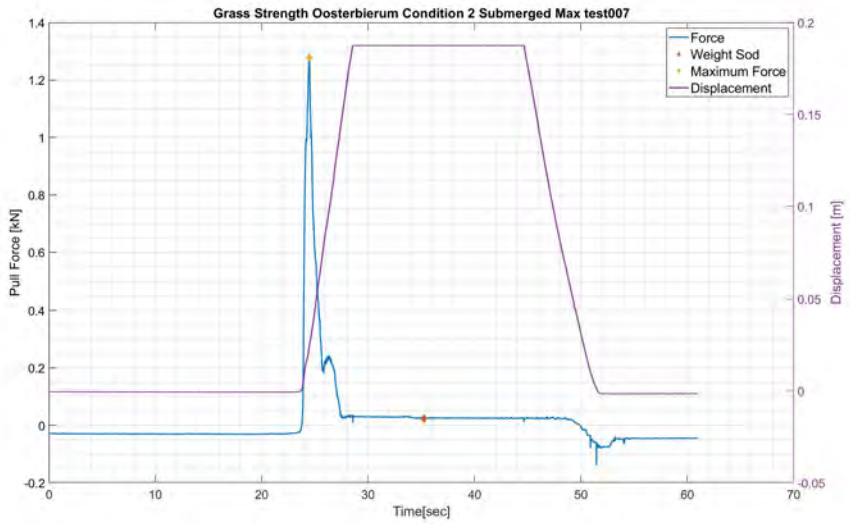


Stress - Strain relation.

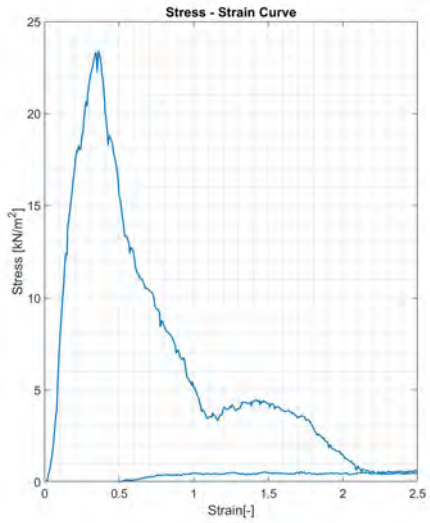
test007

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	1256			
Width Sod	$[cm]$	26			
Weight Sod	$[N]$	24			
Sod Height	$[cm]$	8	6	8	6.8
Root Length	$[cm]$	5	8	8	7.1
Comments					

Figure 4.5: Pictures of tested grass sod.



Measurement of load and displacement

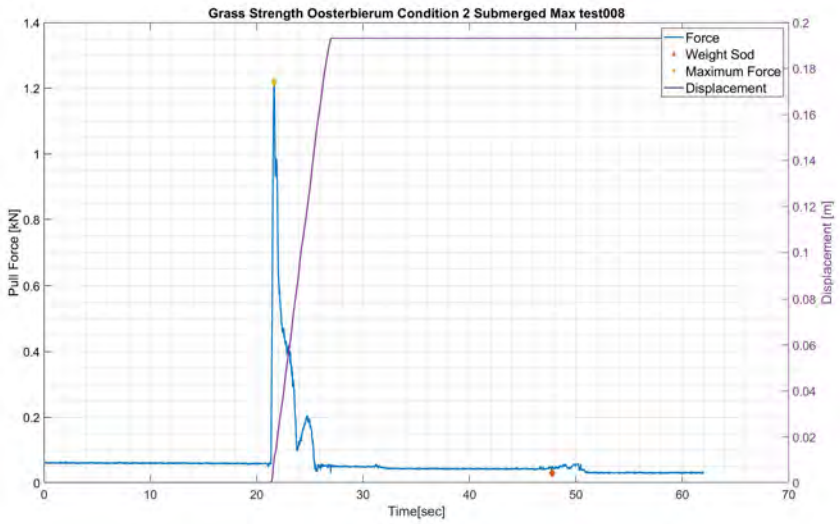


Stress - Strain relation.

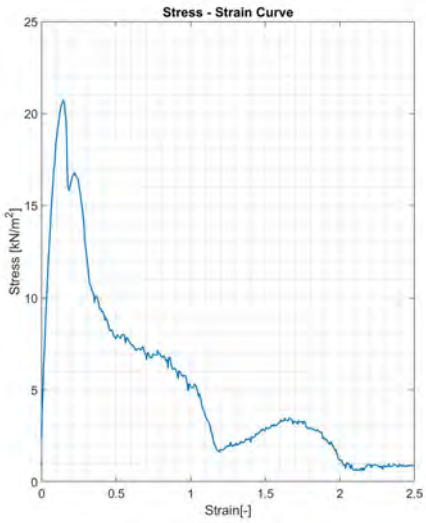
test008

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	1187			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	30			
Sod Height	$[cm]$	8	7	7	7.2
Root Length	$[cm]$	7	7	7	7
Comments					

Figure 4.6: Pictures of tested grass sod.



Measurement of load and displacement

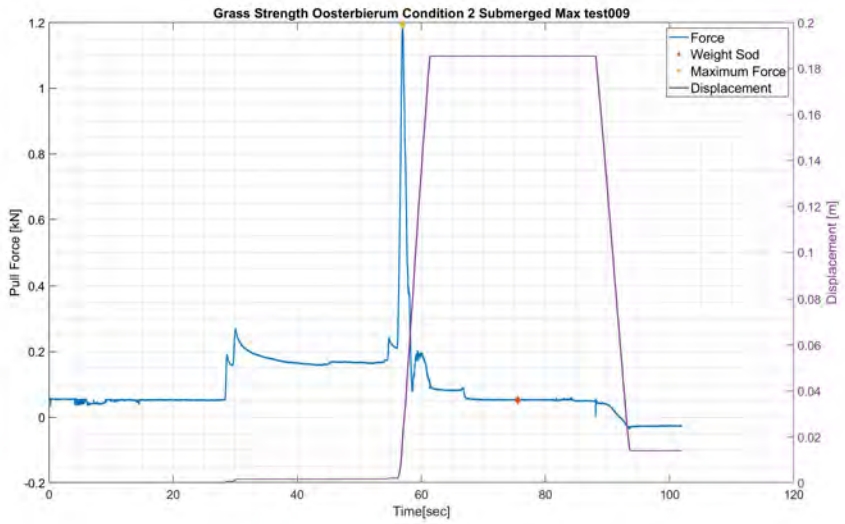


Stress - Strain relation.

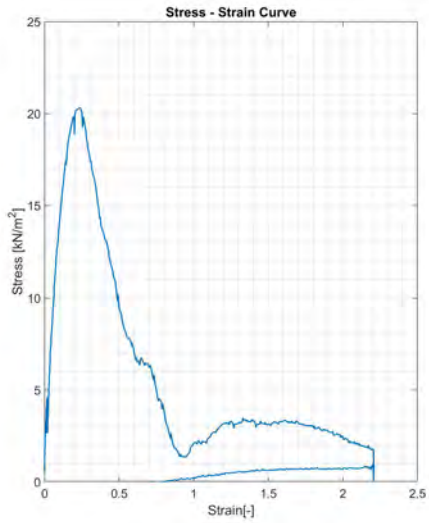
test009

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	1187			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	52			
Sod Height	$[cm]$	10	8	8	8.4
Root Length	$[cm]$	6	8	8	7.6
Comments					

Figure 4.7: Pictures of tested grass sod.



Measurement of load and displacement

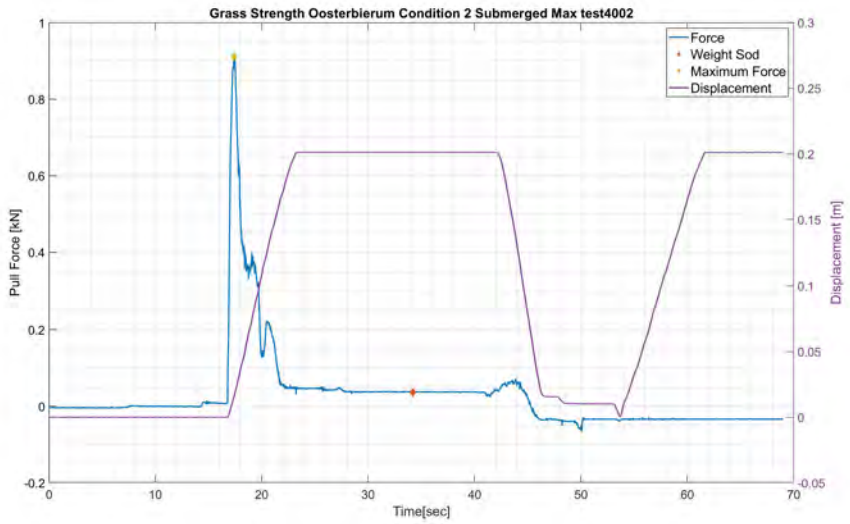


Stress - Strain relation.

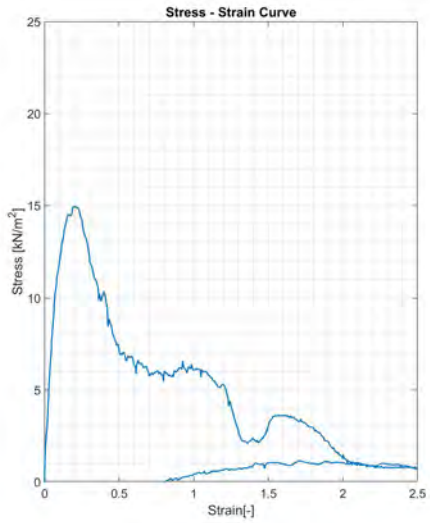
test4002

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	907			
Width Sod	$[cm]$	29			
Weight Sod	$[N]$	48			
Sod Height	$[cm]$	9	7	6	8
Root Length	$[cm]$	6	6	6	6
Comments					

Figure 4.8: Pictures of tested grass sod.



Measurement of load and displacement



Stress - Strain relation.

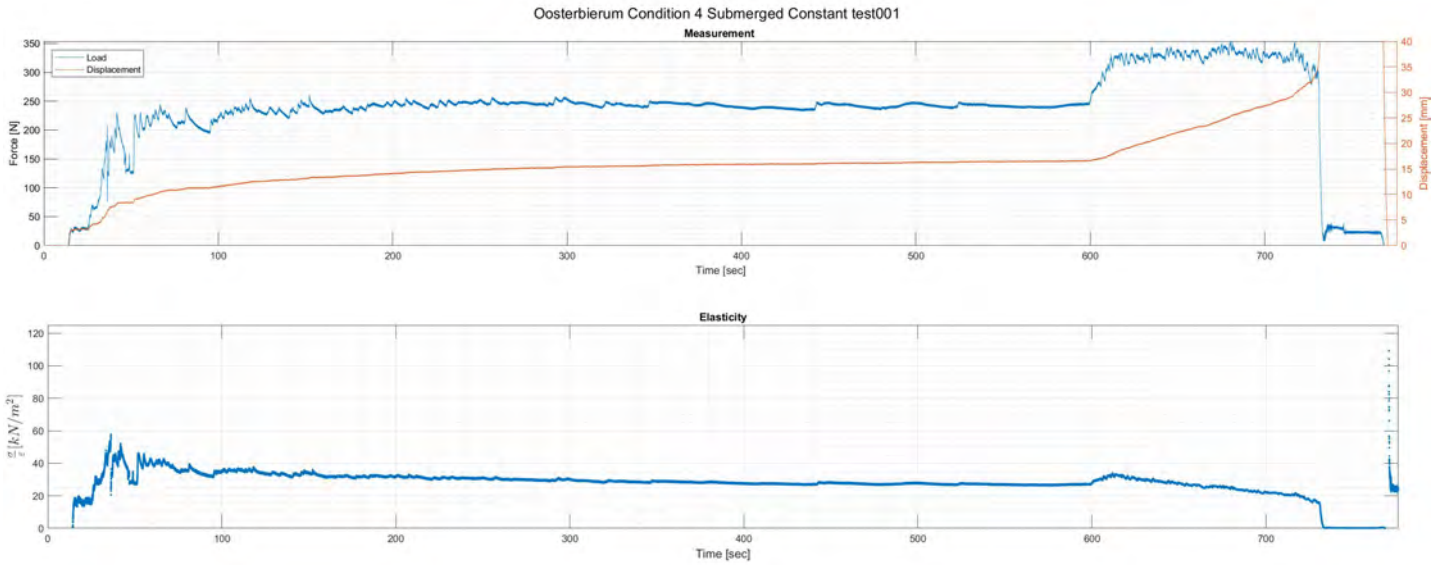
Submerged Condition 2 Constant

	Time to reach 80% of displacement $[sec]$	$E\,[kN/m^2]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test006	79	63.91	2.2	21.0	7.7	7.0
test005	94	34.02	3.7	21.0	7.6	5.4
test004	119	34.85	3.8	21.0	7.2	7.0
test003	144	32.08	NaN	21.0	7.9	6.7
test002	200	28.17	3.2	21.0	7.9	7.0
test001	118	27.03	6.0	21.0	10.2	4.4
mean	126	36.68	3.8	21.0	8.1	6.2
median	118	33.05	3.7	21.0	7.8	6.8
75th percentile	144	34.85	4.3	21.0	7.9	7.0
25th percentile	94	28.17	3.0	21.0	7.6	5.4

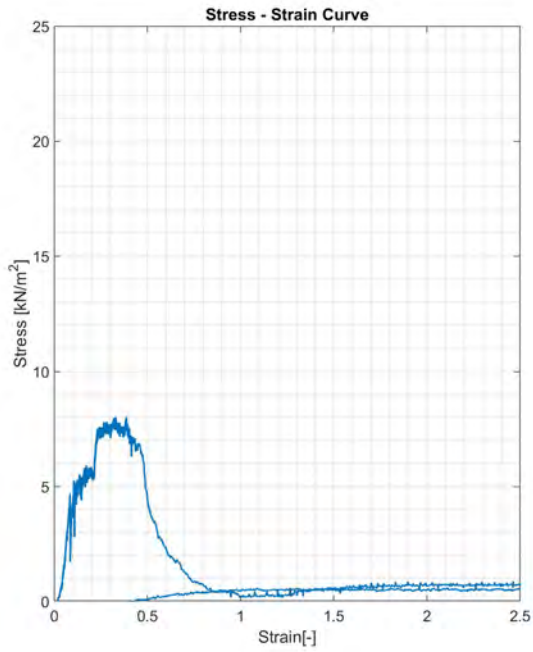
test001

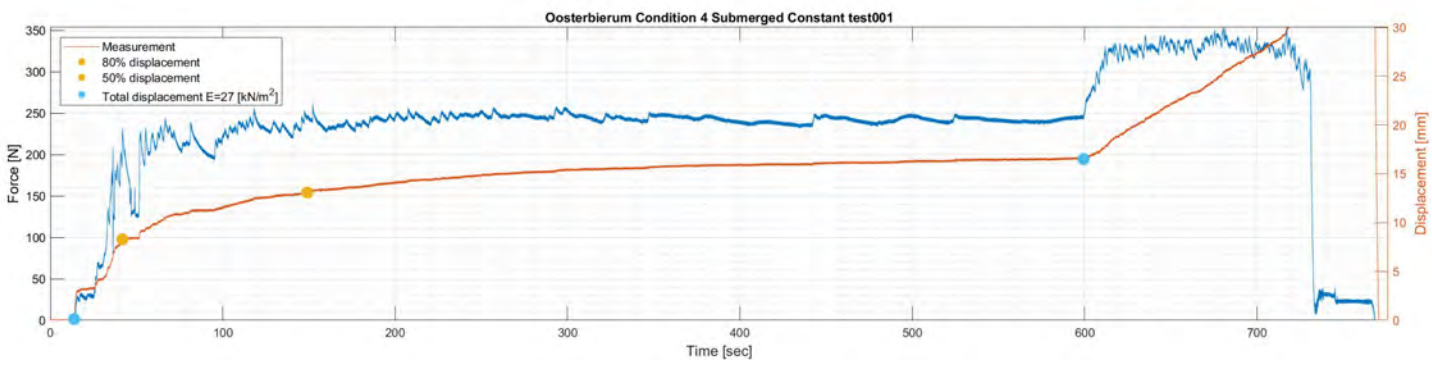
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	27.03			
Time to reach 80% of displacement	$[sec]$	118			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	22			
Sod Height	$[cm]$	9	8	7	7.7
Root Length	$[cm]$	7	7	7	7
Comments					

Figure 5.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



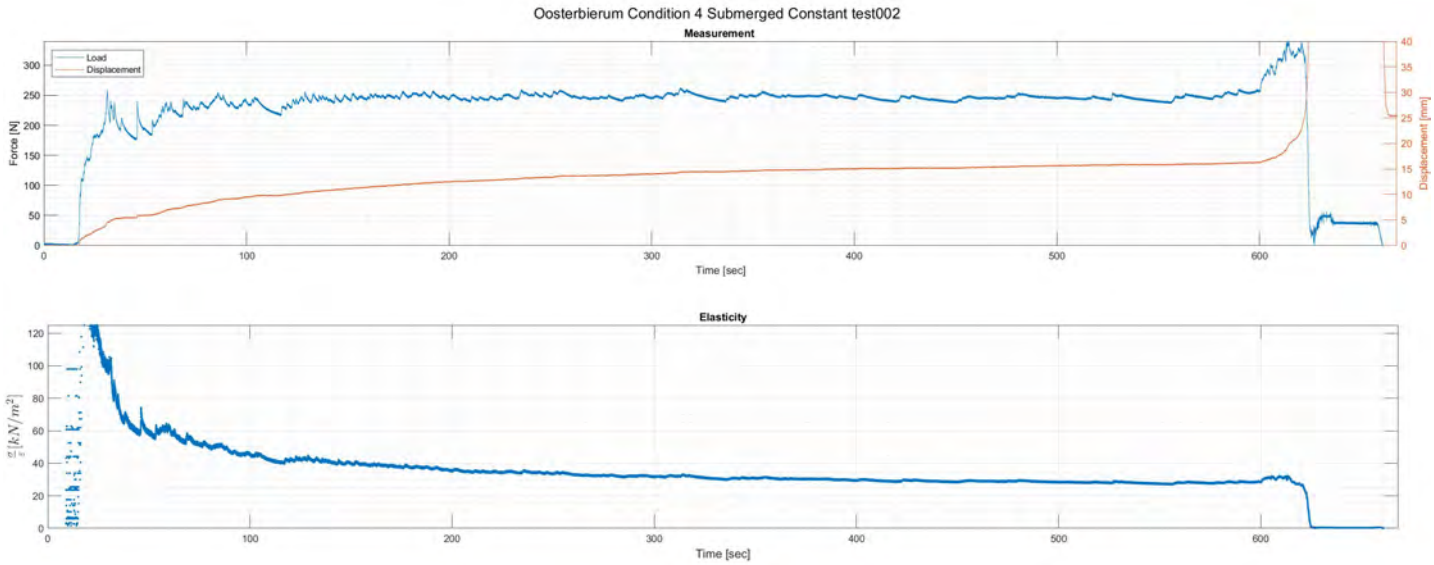


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

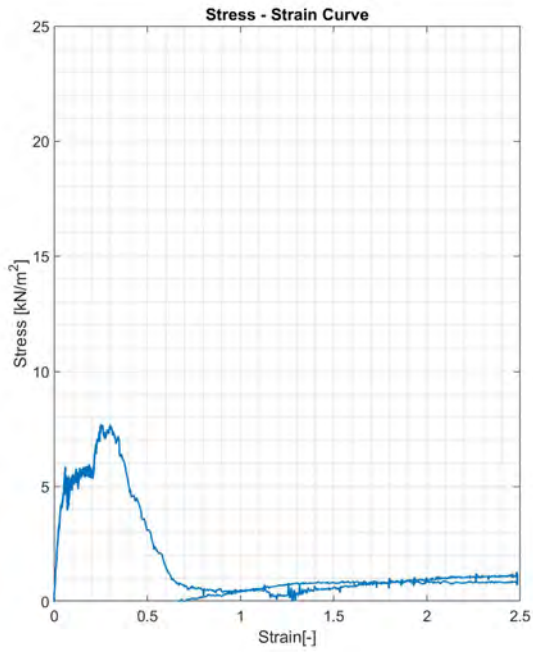
test002

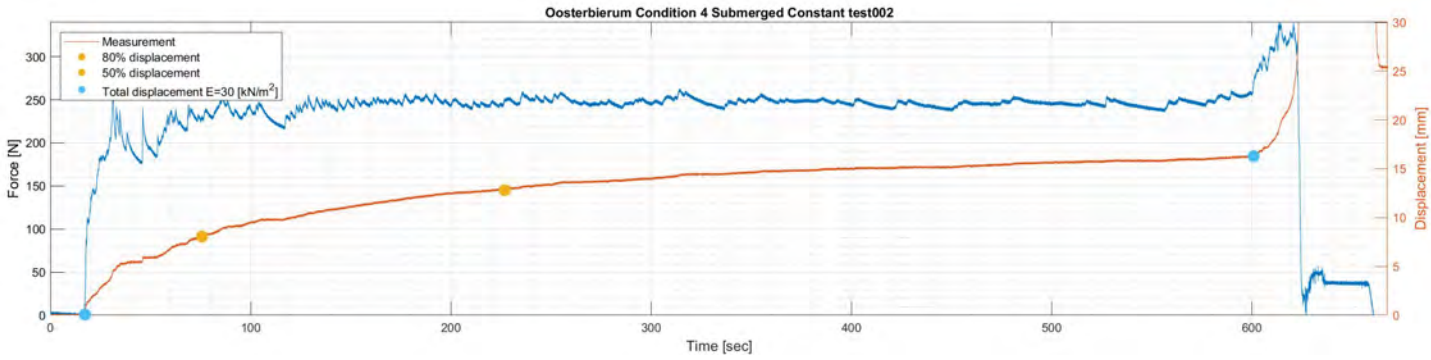
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	28.17			
Time to reach 80% of displacement	$[sec]$	200			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	37			
Sod Height	$[cm]$	10	8	6	7.6
Root Length	$[cm]$	4	6	6	5.4
Comments					

Figure 5.2: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



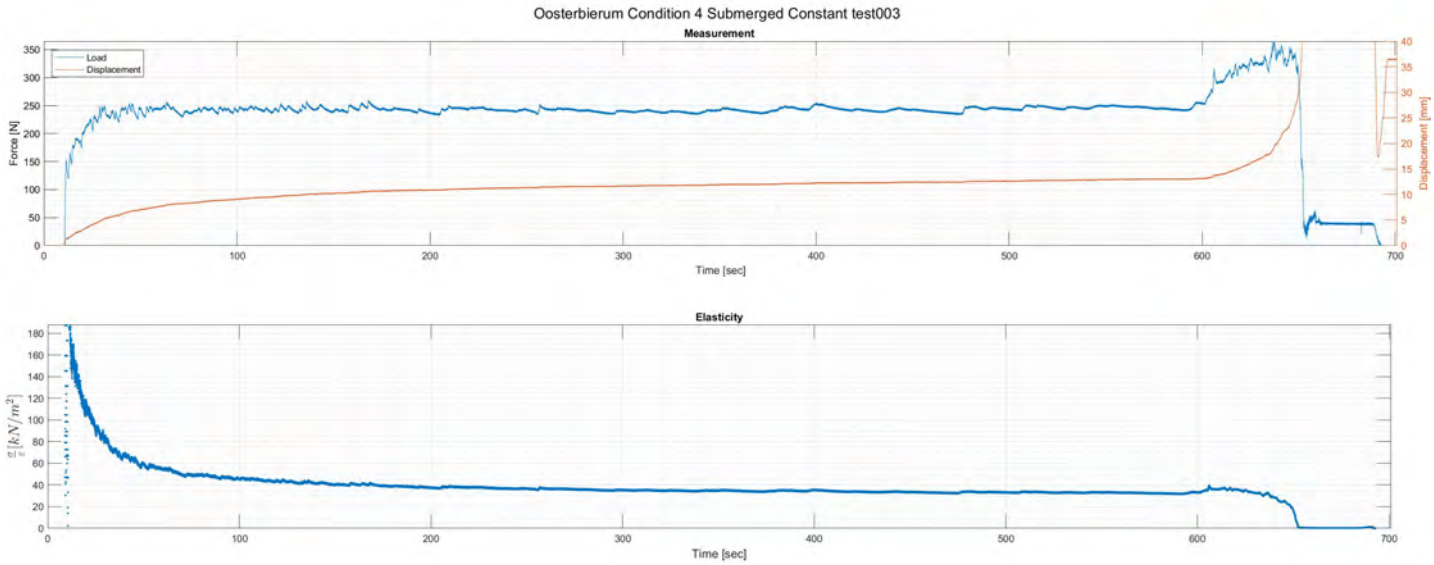


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

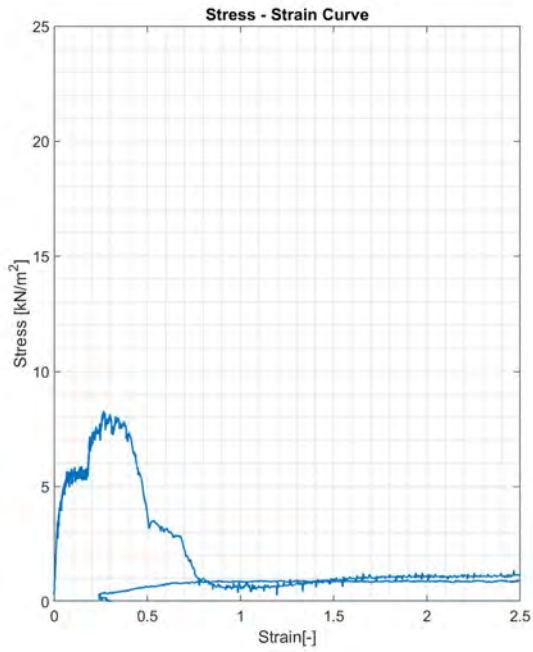
test003

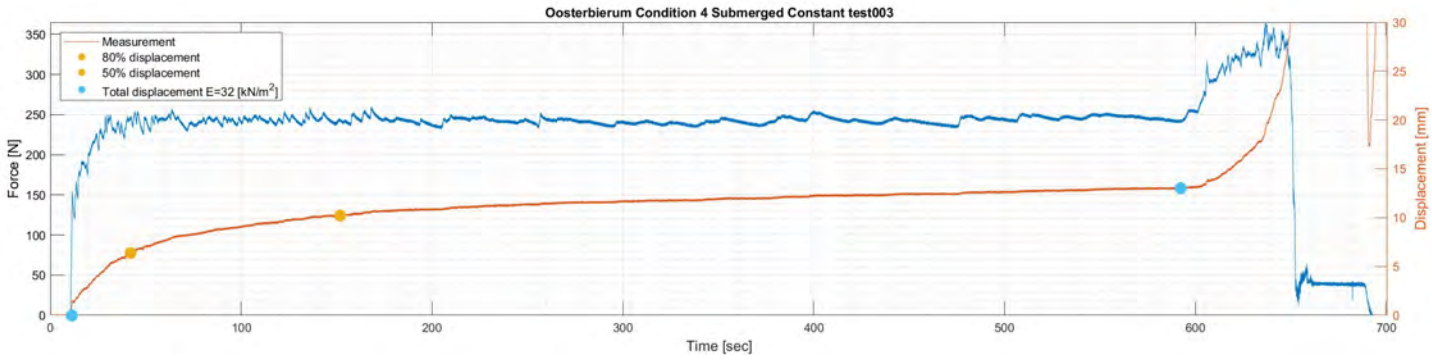
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	32.08			
Time to reach 80% of displacement	$[sec]$	144			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	38			
Sod Height	$[cm]$	9	7	0	7.2
Root Length	$[cm]$	7	7	0	7
Comments					

Figure 5.3: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



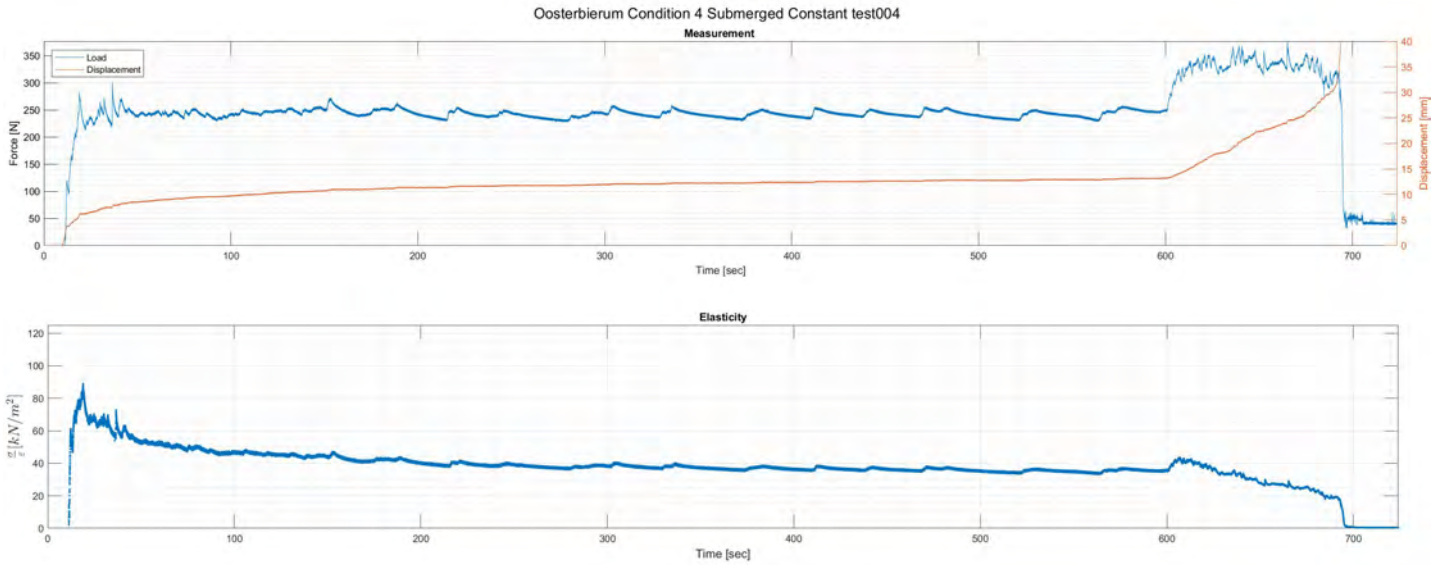


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

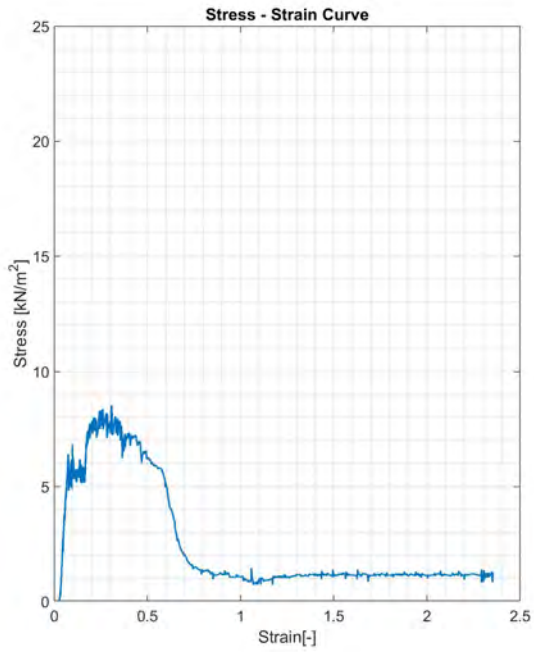
test004

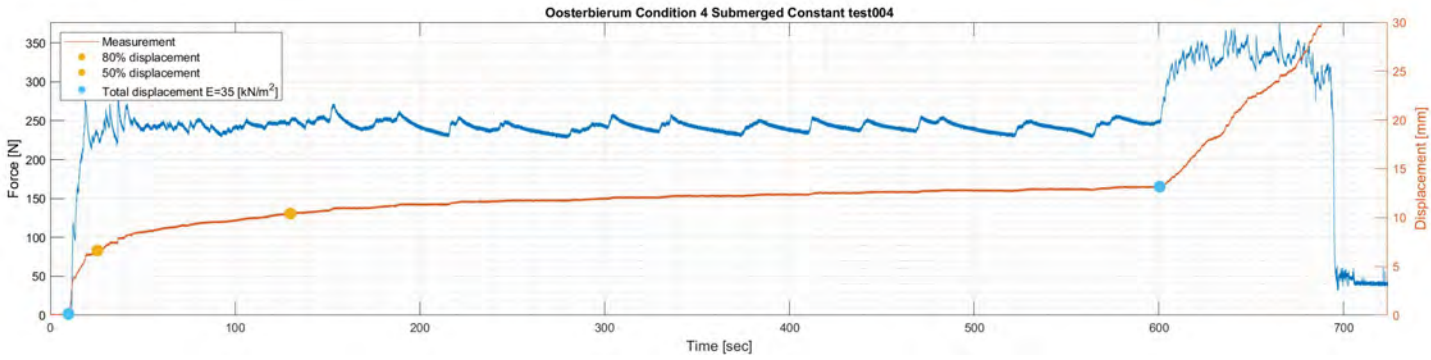
		value 1	value 2	value 3	mean
Date		21-3-2019			
E	$[kN/m^2]$	34.85			
Time to reach 80% of displacement	$[sec]$	119			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	NaN			
Sod Height	$[cm]$	10	7	0	7.9
Root Length	$[cm]$	6	7	0	6.7
Comments					

Figure 5.4: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



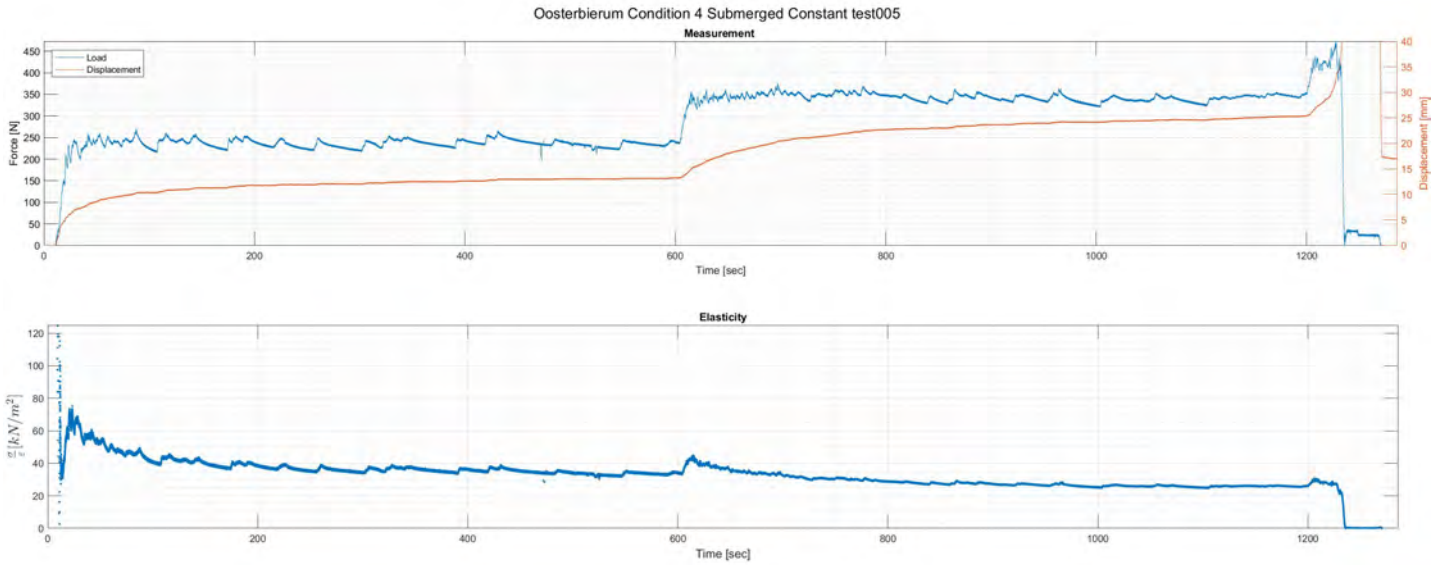


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

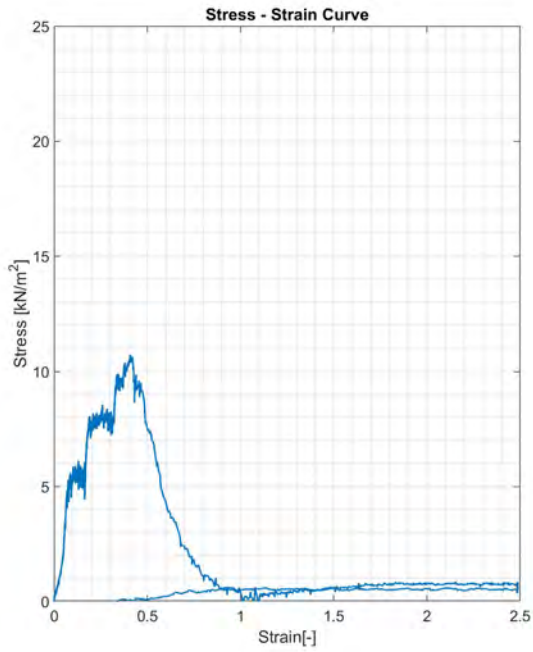
test005

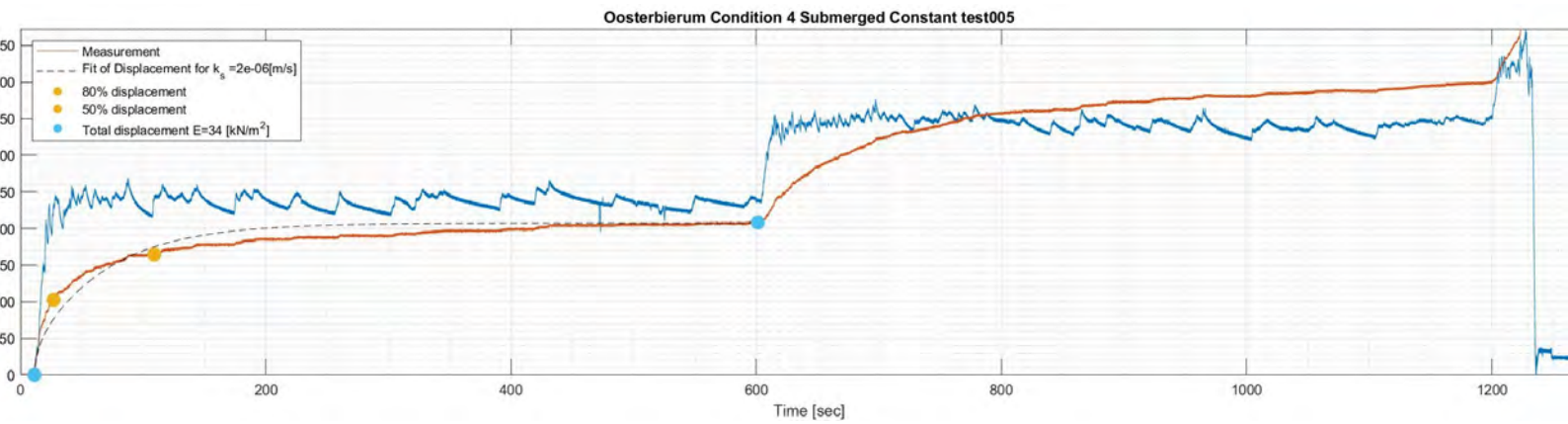
		value 1	value 2	value 3	mean
Date		21-3-2019			
E	$[kN/m^2]$	34.02			
Time to reach 80% of displacement	$[sec]$	94			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	32			
Sod Height	$[cm]$	9	8	7	7.9
Root Length	$[cm]$	7	7	7	7
Comments					

Figure 5.5: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



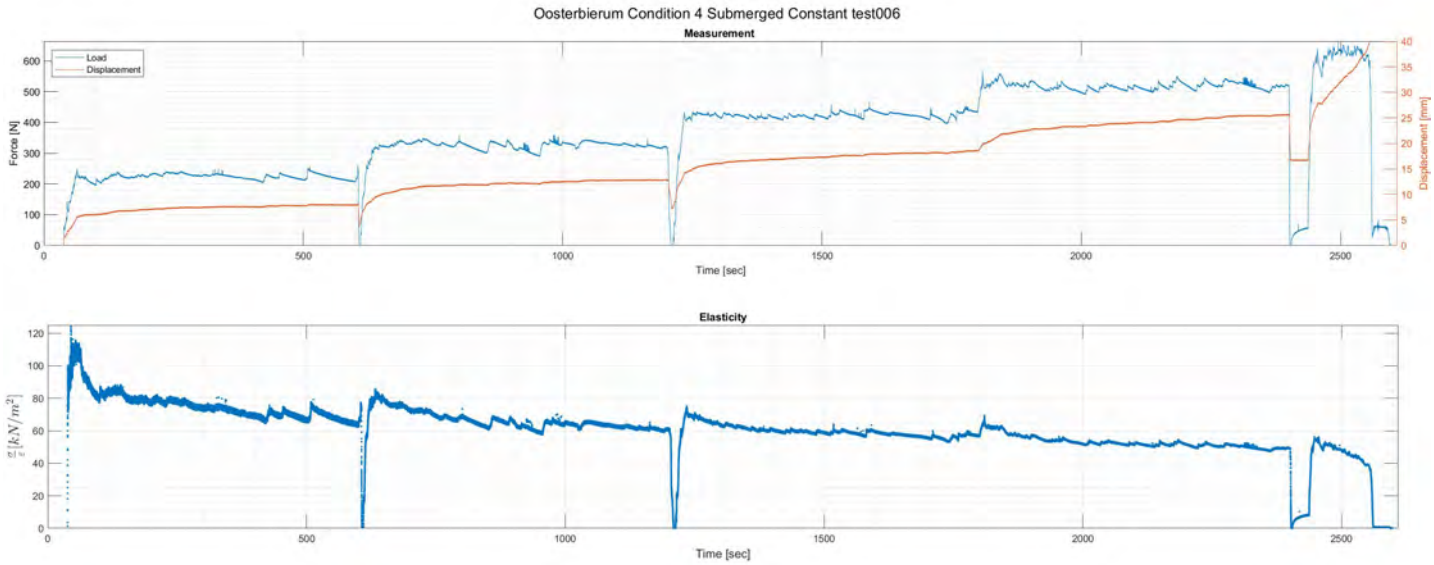


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

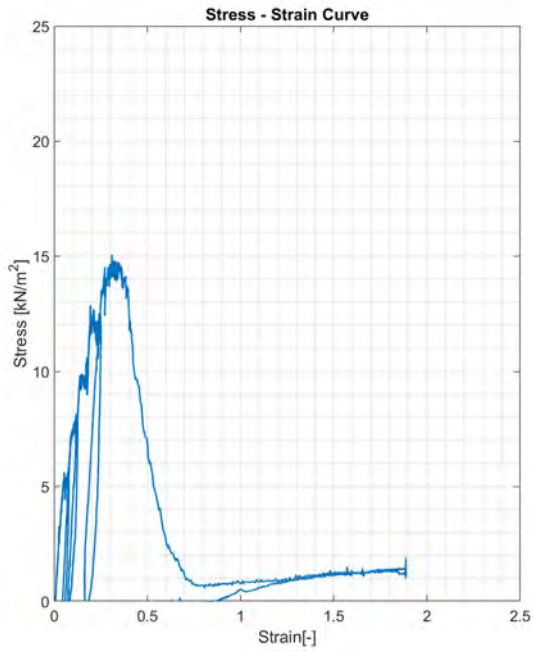
test006

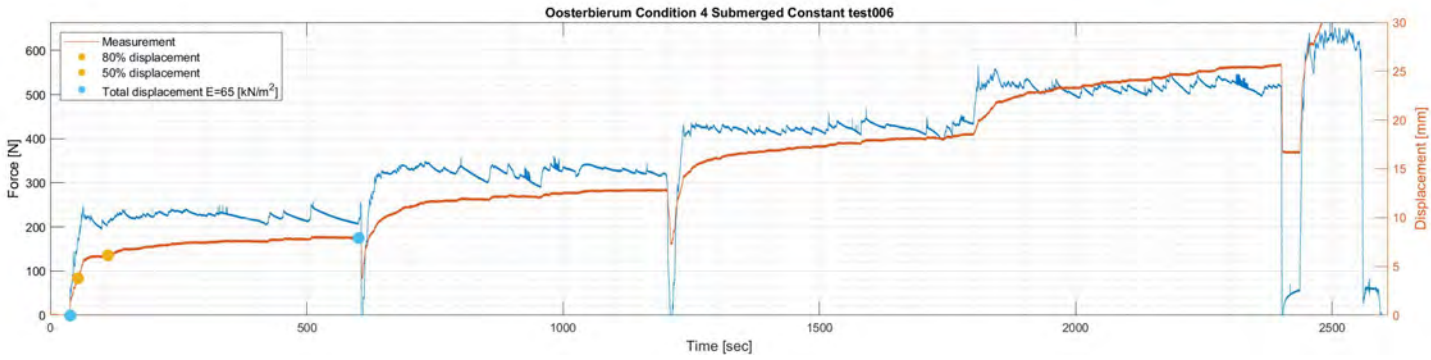
		value 1	value 2	value 3	mean
Date		18-4-2019			
E	$[kN/m^2]$	63.91			
Time to reach 80% of displacement	$[sec]$	79			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	60			
Sod Height	$[cm]$	14	10	5	10.2
Root Length	$[cm]$	3	5	5	4.4
Comments					

Figure 5.6: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.





Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

Submerged Condition 4 Cyclic

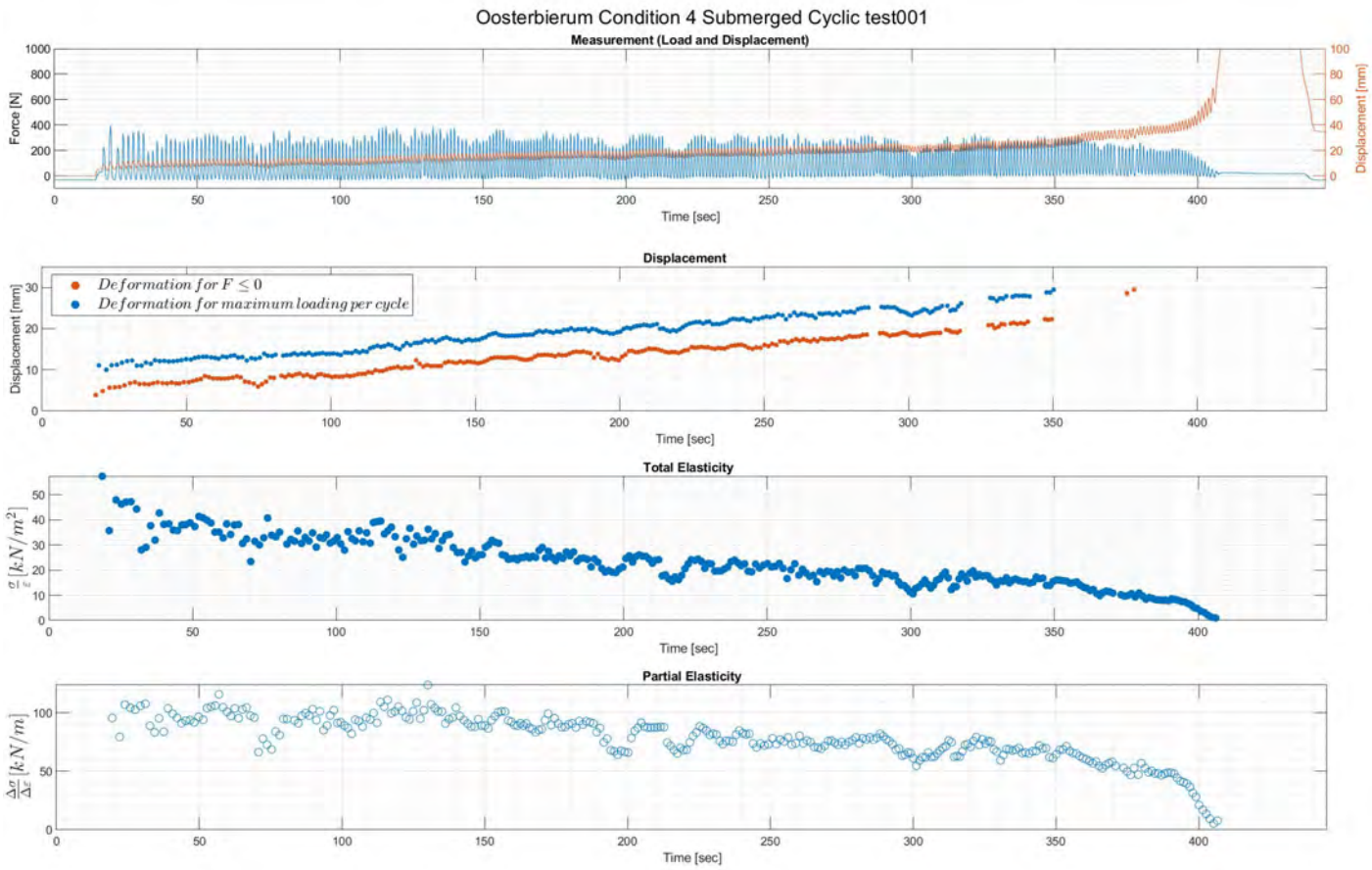
	Growth rate $\frac{\Delta U}{n}$ $[mm]$						Load					
	Plastic deformation			Maximum deformation			Mean			Mean maximum		
Load block	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800
test001	7.42e-02	NaN	NaN	9.02e-02	NaN	NaN	1.31e+02	NaN	NaN	2.75e+02	NaN	NaN
test002	4.01e-02	NaN	NaN	5.47e-02	NaN	NaN	1.45e+02	NaN	NaN	3.10e+02	NaN	NaN
test003	1.03e-01	NaN	NaN	1.27e-01	NaN	NaN	1.40e+02	NaN	NaN	2.91e+02	NaN	NaN
test004	8.24e-03	NaN	NaN	1.19e-02	NaN	NaN	1.01e+02	NaN	NaN	2.06e+02	NaN	NaN
test005	3.54e-03	2.03e-01	NaN	5.03e-03	3.53e-01	NaN	1.25e+02	1.94e+02	NaN	2.64e+02	3.81e+02	NaN
test006	2.24e-03	4.35e-02	NaN	1.62e-03	6.11e-02	NaN	1.25e+02	3.05e+02	NaN	2.62e+02	6.12e+02	NaN
test007	2.80e-03	6.17e-03	NaN	3.31e-03	2.32e-02	NaN	1.42e+02	2.66e+02	NaN	2.82e+02	5.10e+02	NaN
test009	8.07e-03	5.76e-02	NaN	1.40e-02	9.43e-02	NaN	1.53e+02	1.98e+02	NaN	3.00e+02	3.91e+02	NaN
test010	3.10e-03	6.67e-02	NaN	3.45e-03	1.09e-01	NaN	7.45e+01	1.71e+02	NaN	1.59e+02	3.49e+02	NaN
test011	2.22e-03	2.78e-02	NaN	2.92e-03	3.93e-02	NaN	9.73e+01	2.44e+02	NaN	2.12e+02	4.83e+02	NaN
test012	1.22e-03	2.58e-03	6.45e-02	1.55e-03	3.59e-03	9.01e-02	8.26e+01	1.90e+02	3.23e+02	1.88e+02	3.92e+02	6.54e+02
mean	2.26e-02	5.82e-02	6.45e-02	2.87e-02	9.76e-02	9.01e-02	1.20e+02	2.24e+02	3.23e+02	2.50e+02	4.45e+02	6.54e+02
median	3.54e-03	4.35e-02	6.45e-02	5.03e-03	6.11e-02	9.01e-02	1.25e+02	1.98e+02	3.23e+02	2.64e+02	3.92e+02	6.54e+02
75th percentile	3.21e-02	6.44e-02	6.45e-02	4.45e-02	1.05e-01	9.01e-02	1.42e+02	2.61e+02	3.23e+02	2.89e+02	5.03e+02	6.54e+02
25th percentile	2.38e-03	1.16e-02	6.45e-02	3.02e-03	2.73e-02	9.01e-02	9.81e+01	1.91e+02	3.23e+02	2.07e+02	3.83e+02	6.54e+02

	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test001	2.3	21.0	7.1	7.0
test002	3.0	21.0	7.1	6.9
test003	2.8	21.0	6.3	1.9
test004	-3.0	21.0	7.4	8.0
test005	4.4	21.0	7.4	7.0
test006	4.1	21.0	7.9	7.5
test007	4.1	21.0	7.7	6.8
test009	5.0	21.0	8.6	6.6
test010	3.1	21.0	8.6	8.0
test011	4.5	21.0	8.7	8.6
test012	5.6	21.0	9.3	5.1
Mean	3.3	21	7.8	6.7
Median	4.1	21	7.7	7
75th percentile	4.4	21	8.6	7.9
25th percentile	2.9	21	7.2	6.6

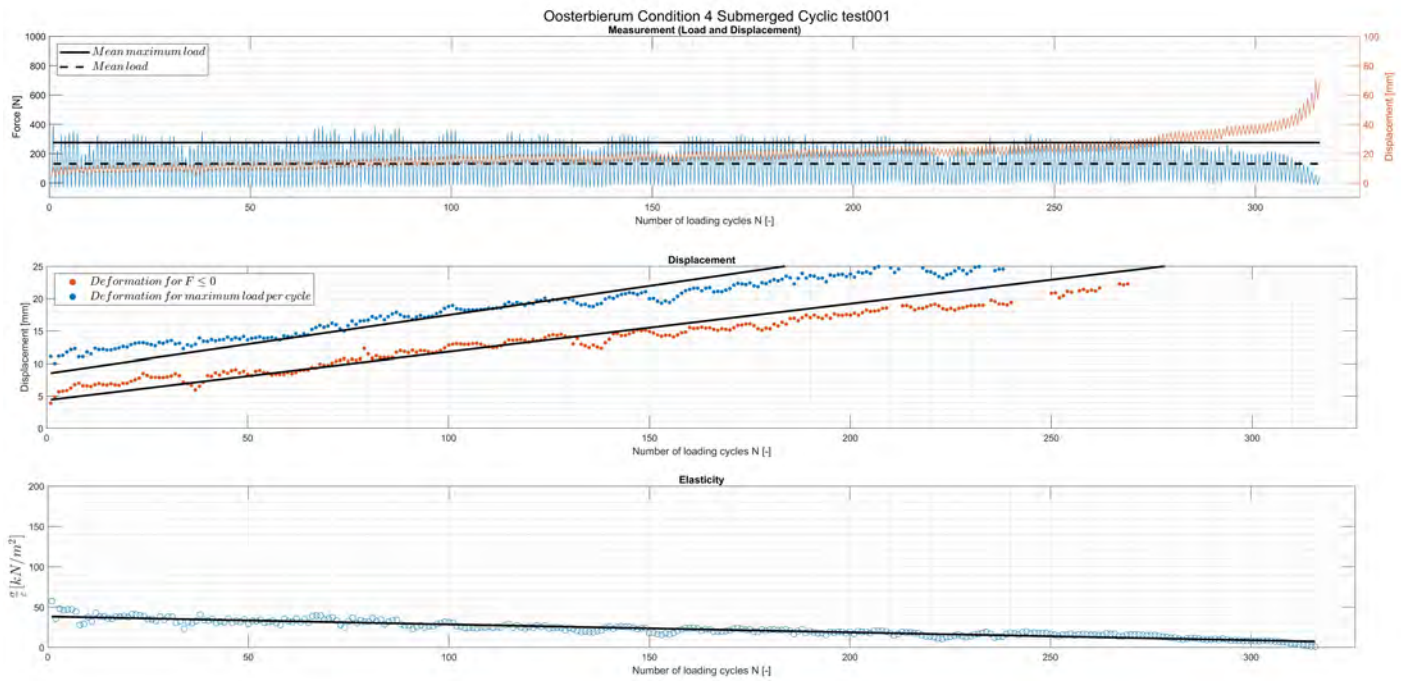
test001

		value 1	value 2	value 3	mean
Date		21-3-2019			
Mean load	$[N]$	1.31e+02			1.31e+02
Mean maximum load	$[N]$	2.75e+02			2.75e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	7.42e-02			
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	9.02e-02			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	23			
Sod Height	$[cm]$	8	7	7	7.1
Root Length	$[cm]$	7	7	7	7
Comments					

Figure 6.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

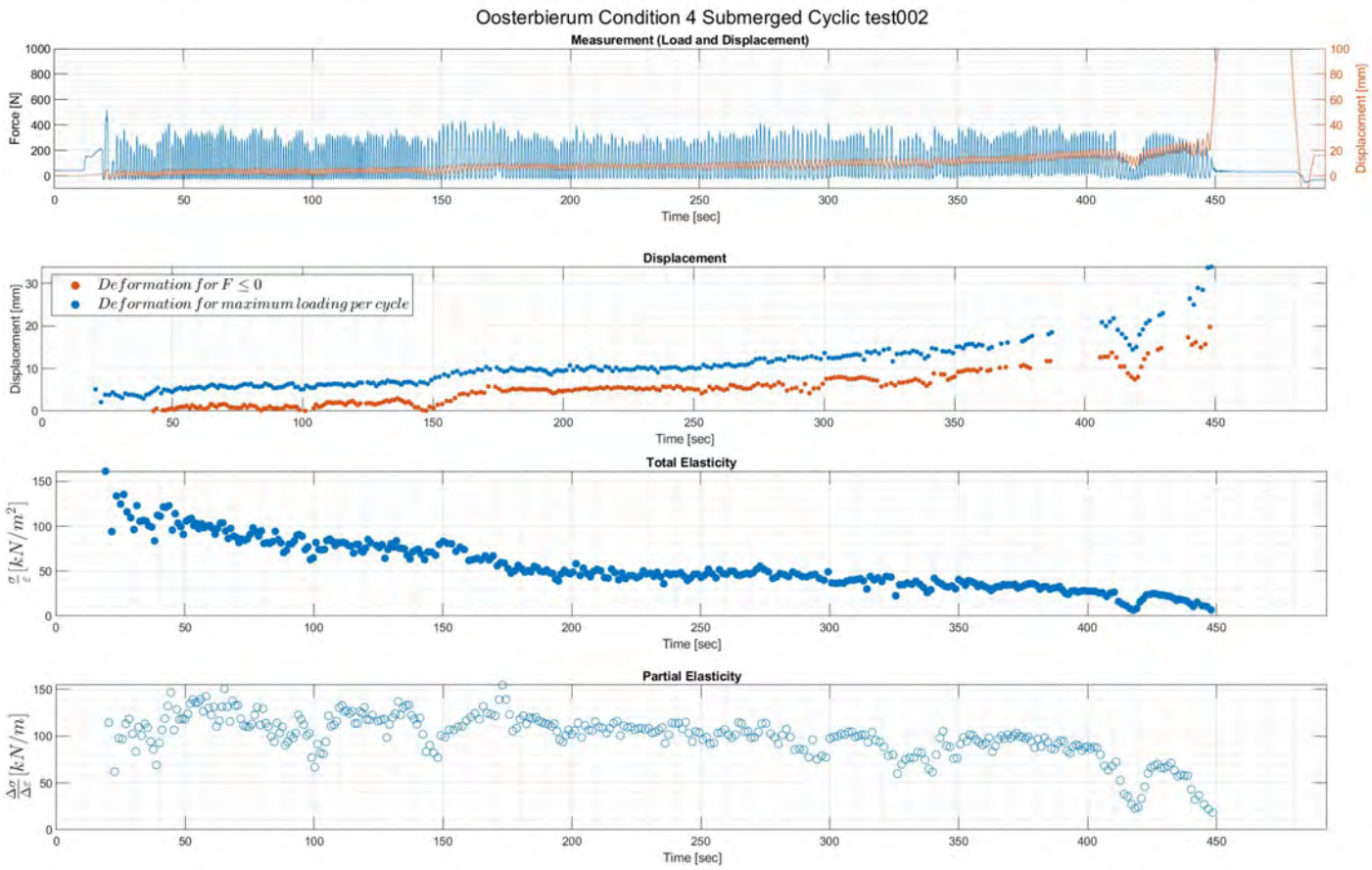


Development of displacement and elasticity are shown as function of number of cycles.

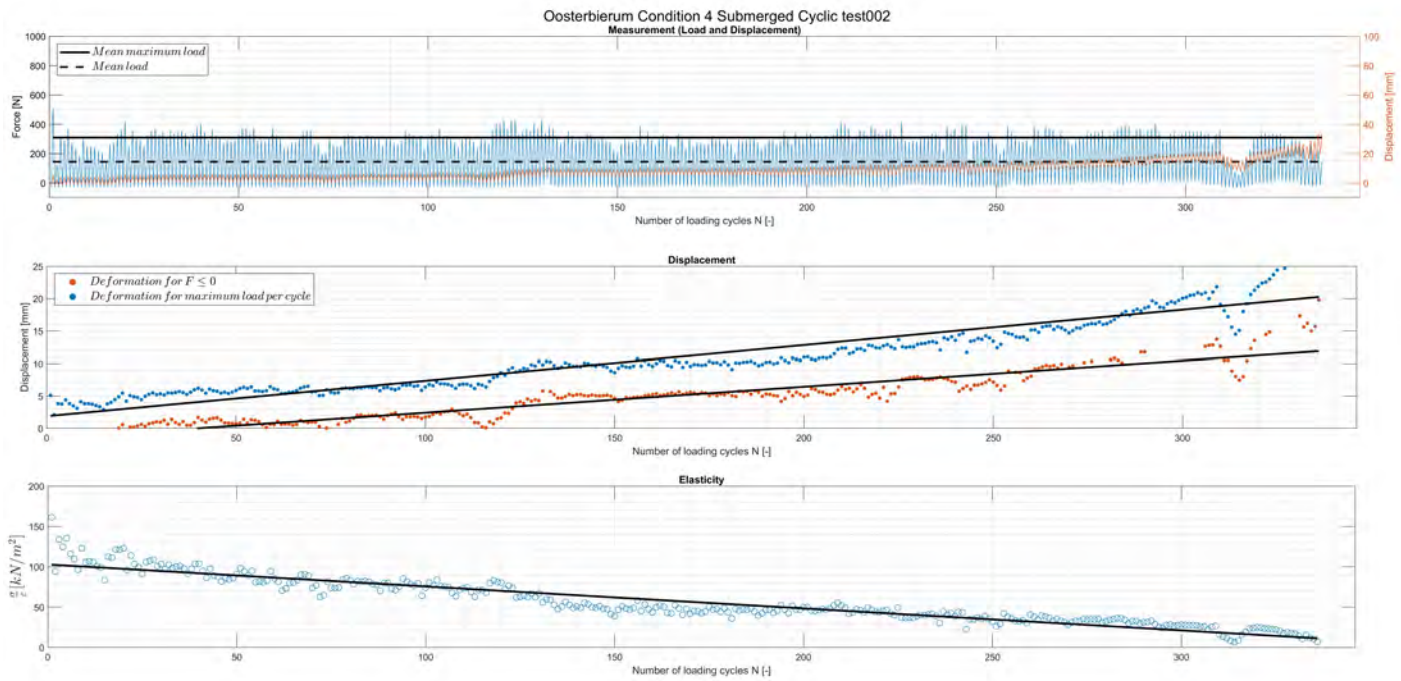
test002

		value 1	value 2	value 3	mean
Date		21-3-2019			
Mean load	$[N]$	1.45e+02			1.45e+02
Mean maximum load	$[N]$	3.10e+02			3.10e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	4.01e-02			
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	5.47e-02			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	30			
Sod Height	$[cm]$	8	7	0	7.1
Root Length	$[cm]$	6	7	0	6.9
Comments					

Figure 6.2: Pictures of tested grass sod.



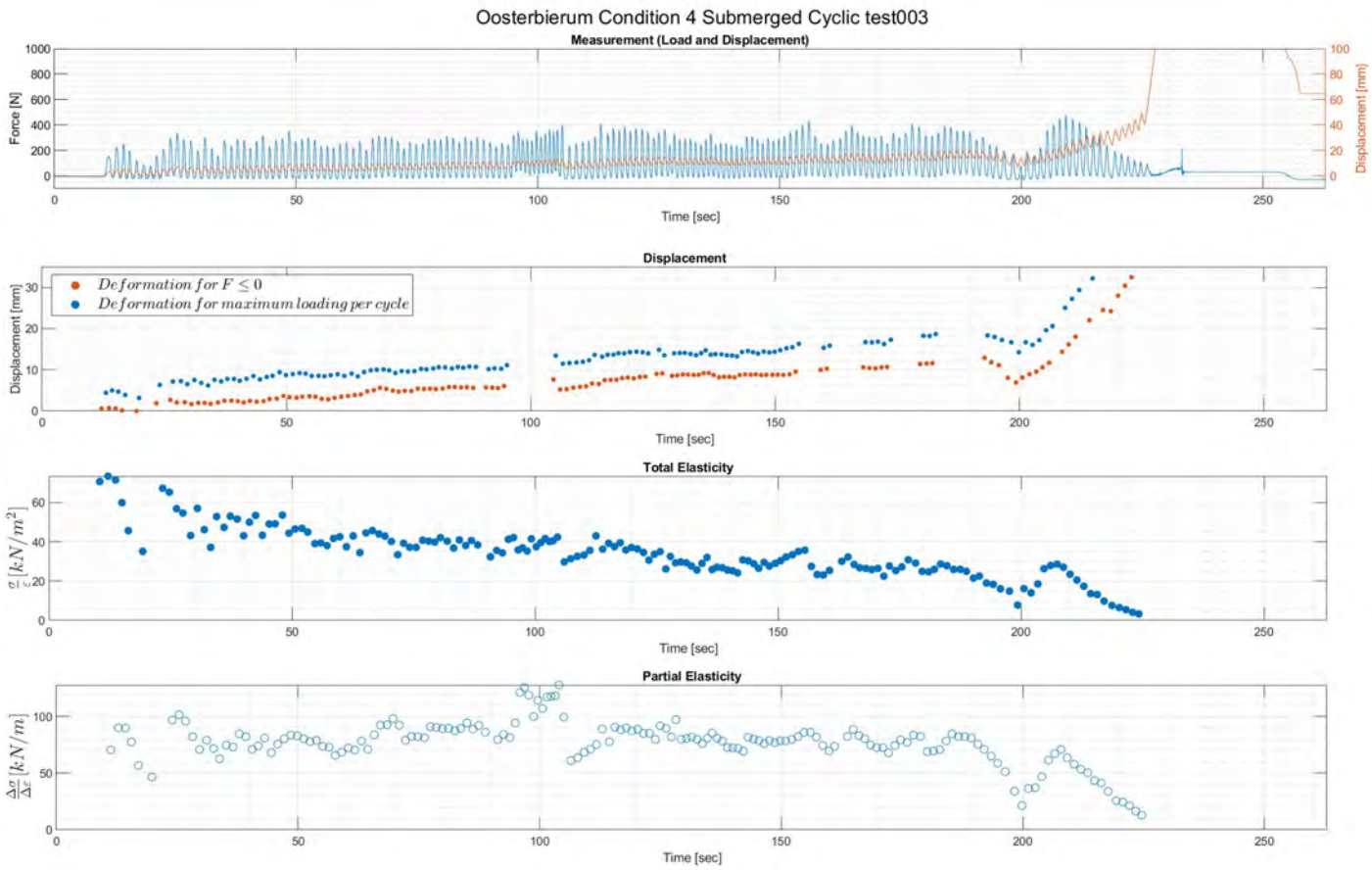
Measurement of load and displacement and resulting elasticity.



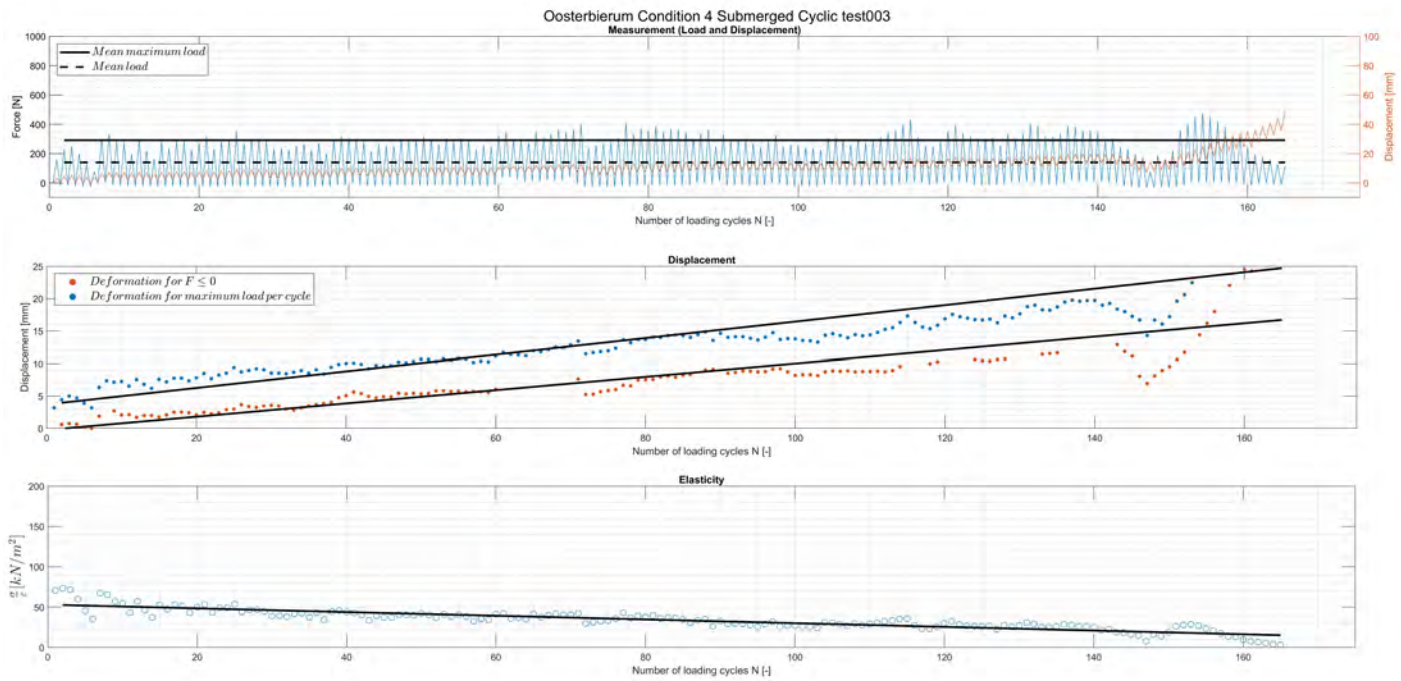
Development of displacement and elasticity are shown as function of number of cycles.

test003

		value 1	value 2	value 3	mean
Date		21-3-2019			
Mean load	$[N]$	1.40e+02			1.40e+02
Mean maximum load	$[N]$	2.91e+02			2.91e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	1.03e-01			
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.27e-01			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	28			
Sod Height	$[cm]$	11	60	0	6.3
Root Length	$[cm]$	5	7	0	1.9
Comments					



Measurement of load and displacement and resulting elasticity.

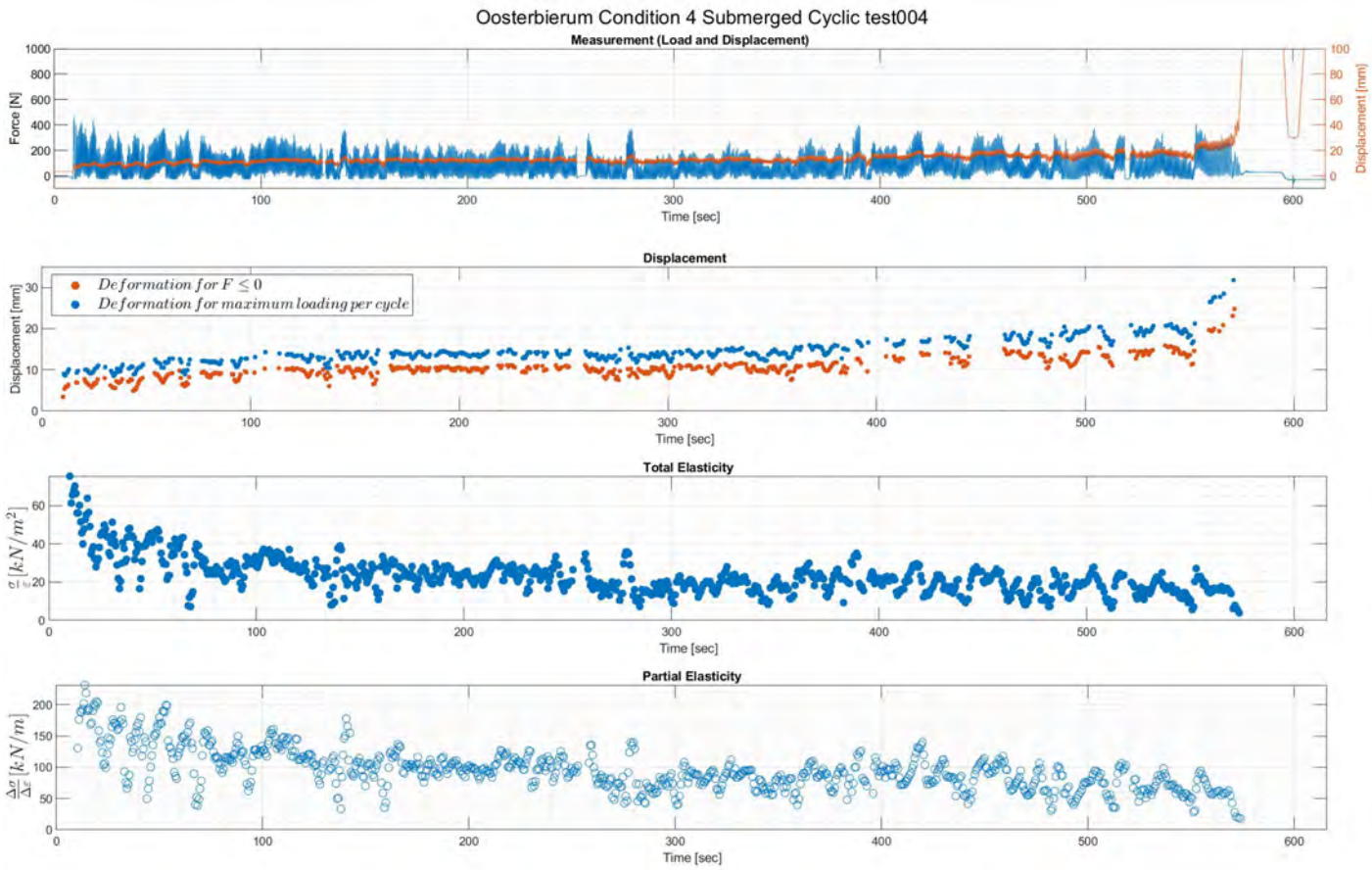


Development of displacement and elasticity are shown as function of number of cycles.

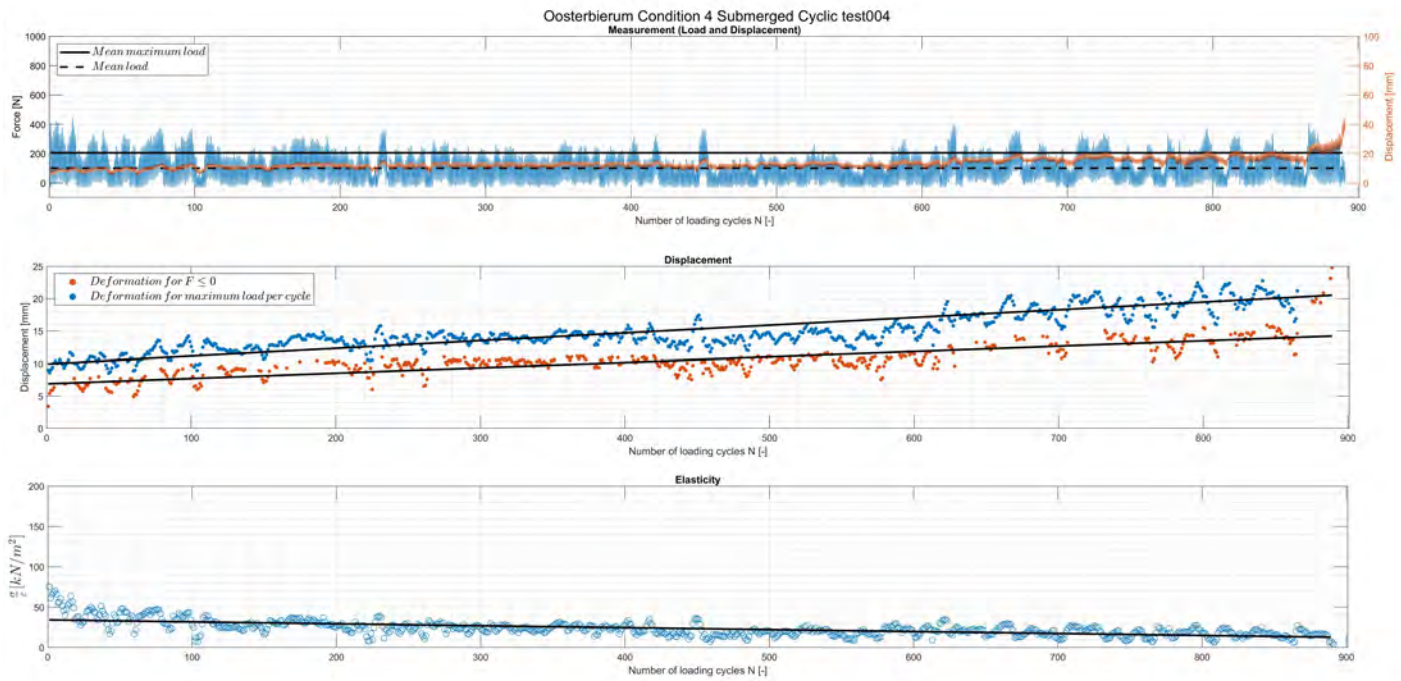
test004

		value 1	value 2	value 3	mean
Date		15-4-2019			
Mean load	$[N]$	1.01e+02			1.01e+02
Mean maximum load	$[N]$	2.06e+02			2.06e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	8.24e-03			
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.19e-02			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	-30			
Sod Height	$[cm]$	8	6	0	7.4
Root Length	$[cm]$	8	8	0	8
Comments					

Figure 6.3: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

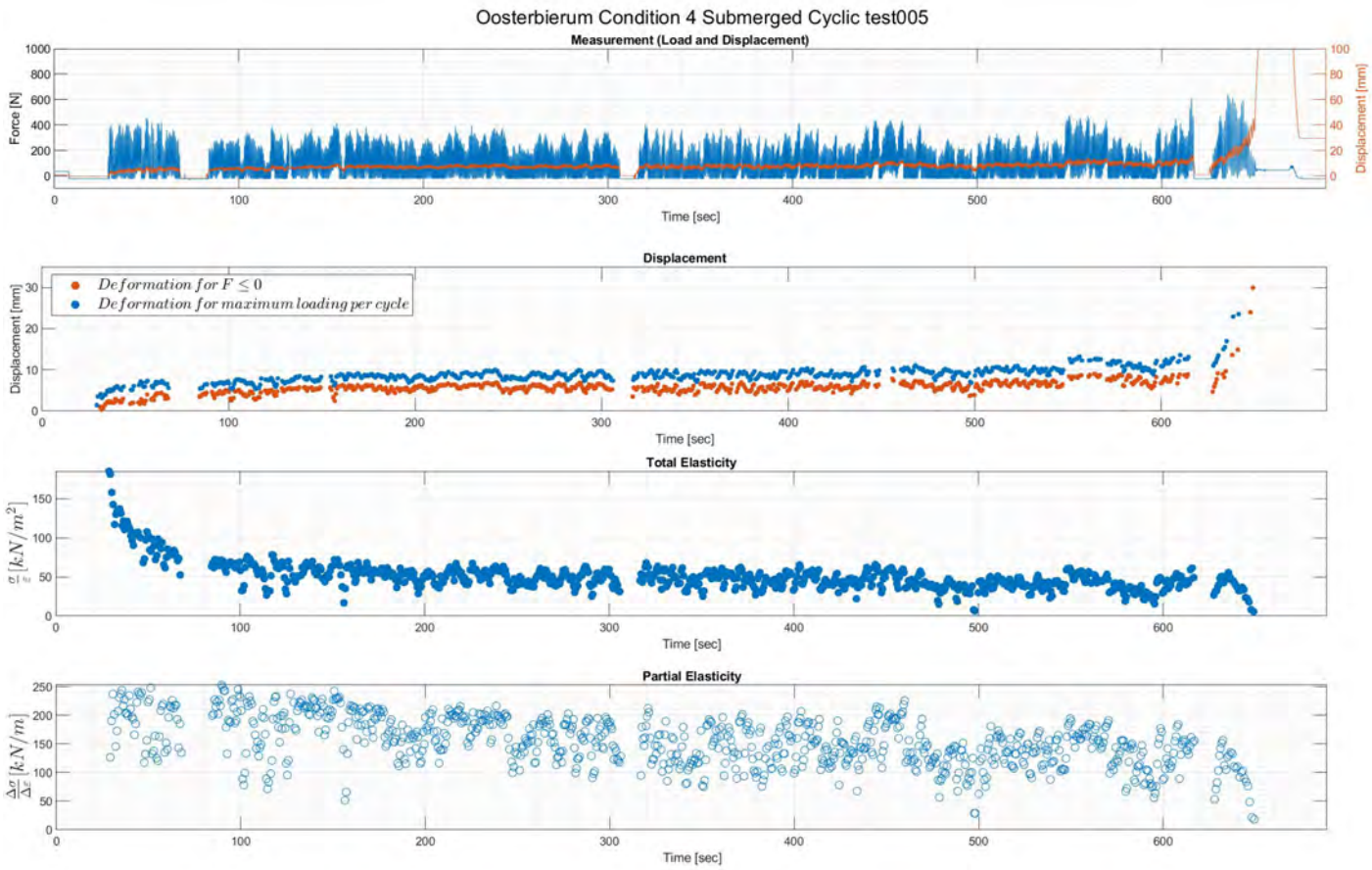


Development of displacement and elasticity are shown as function of number of cycles.

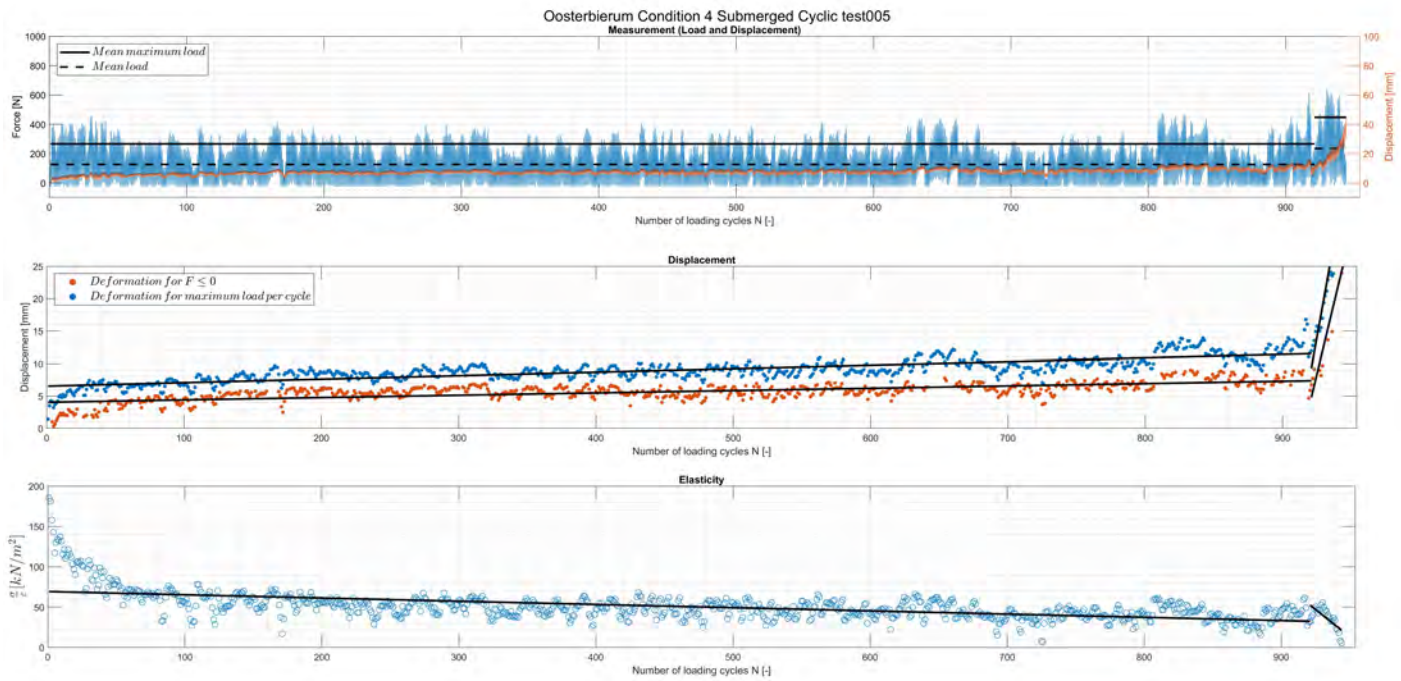
test005

		value 1	value 2	value 3	mean
Date		15-4-2019			
Mean load	$[N]$	1.25e+02	1.94e+02		1.60e+02
Mean maximum load	$[N]$	2.64e+02	3.81e+02		3.22e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	3.54e-03	2.03e-01		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	5.03e-03	3.53e-01		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	44			
Sod Height	$[cm]$	11	7	7	7.4
Root Length	$[cm]$	7	7	7	7
Comments					

Figure 6.4: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

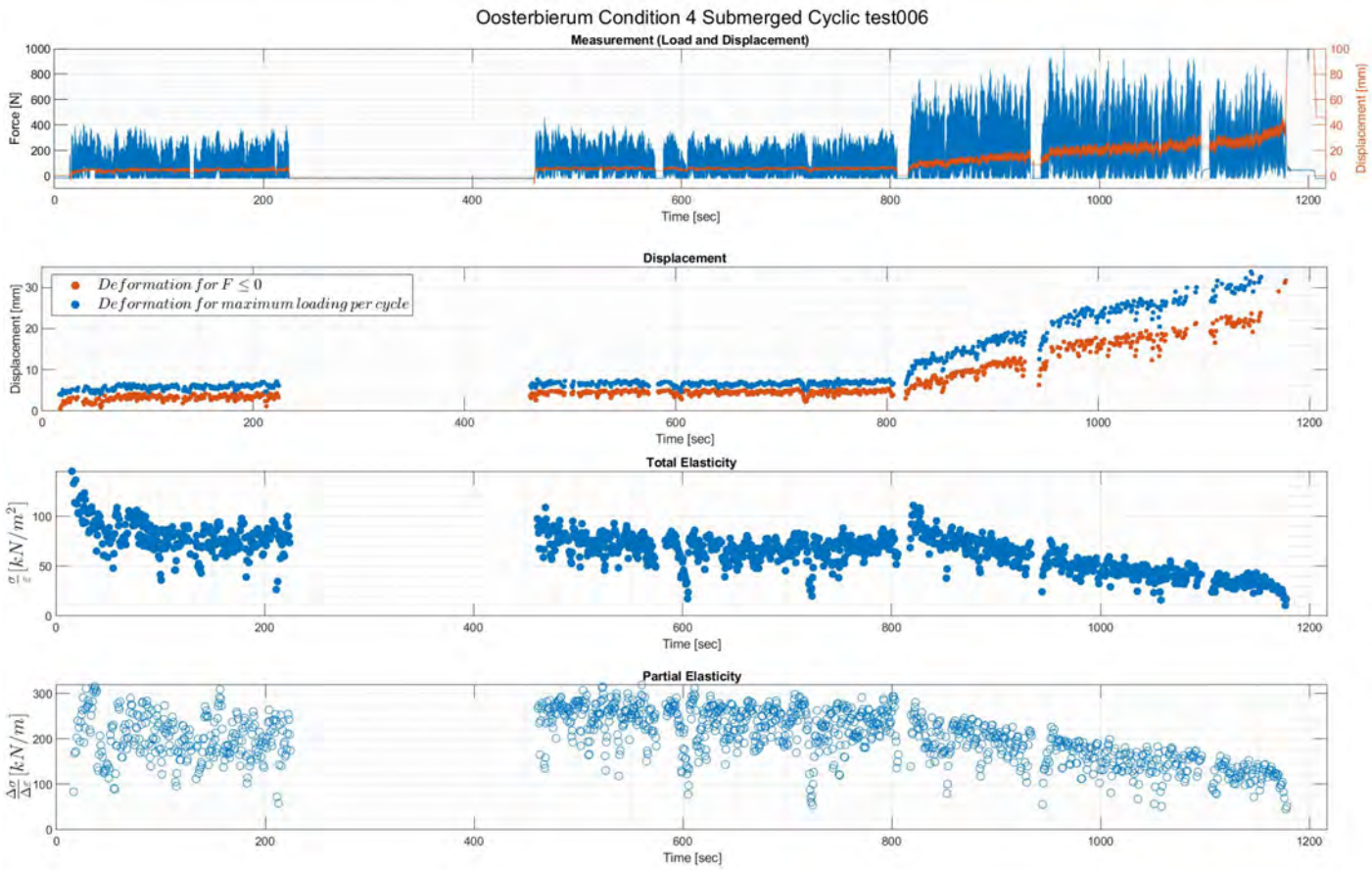


Development of displacement and elasticity are shown as function of number of cycles.

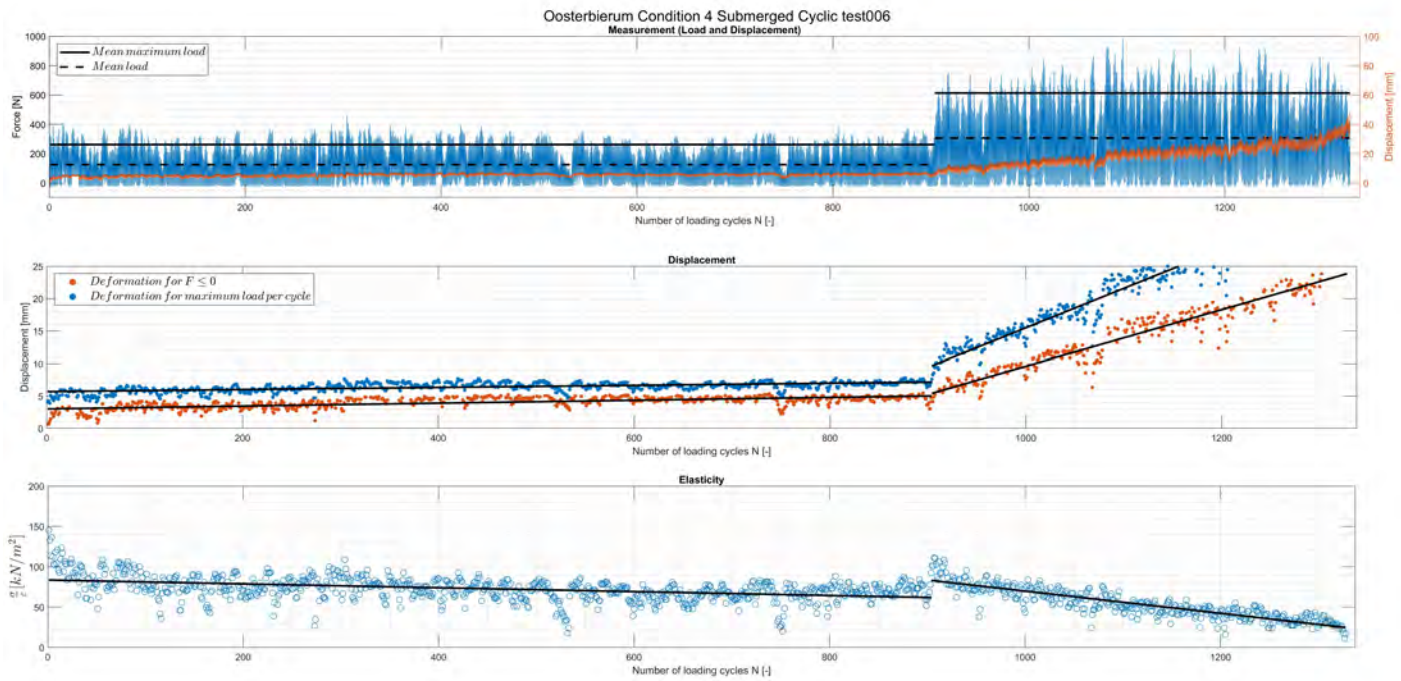
test006

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	1.25e+02	3.05e+02		2.15e+02
Mean maximum load	$[N]$	2.62e+02	6.12e+02		4.37e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	2.24e-03	4.35e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.62e-03	6.11e-02		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	41			
Sod Height	$[cm]$	12	7	8	7.9
Root Length	$[cm]$	3	8	8	7.5
Comments					

Figure 6.5: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

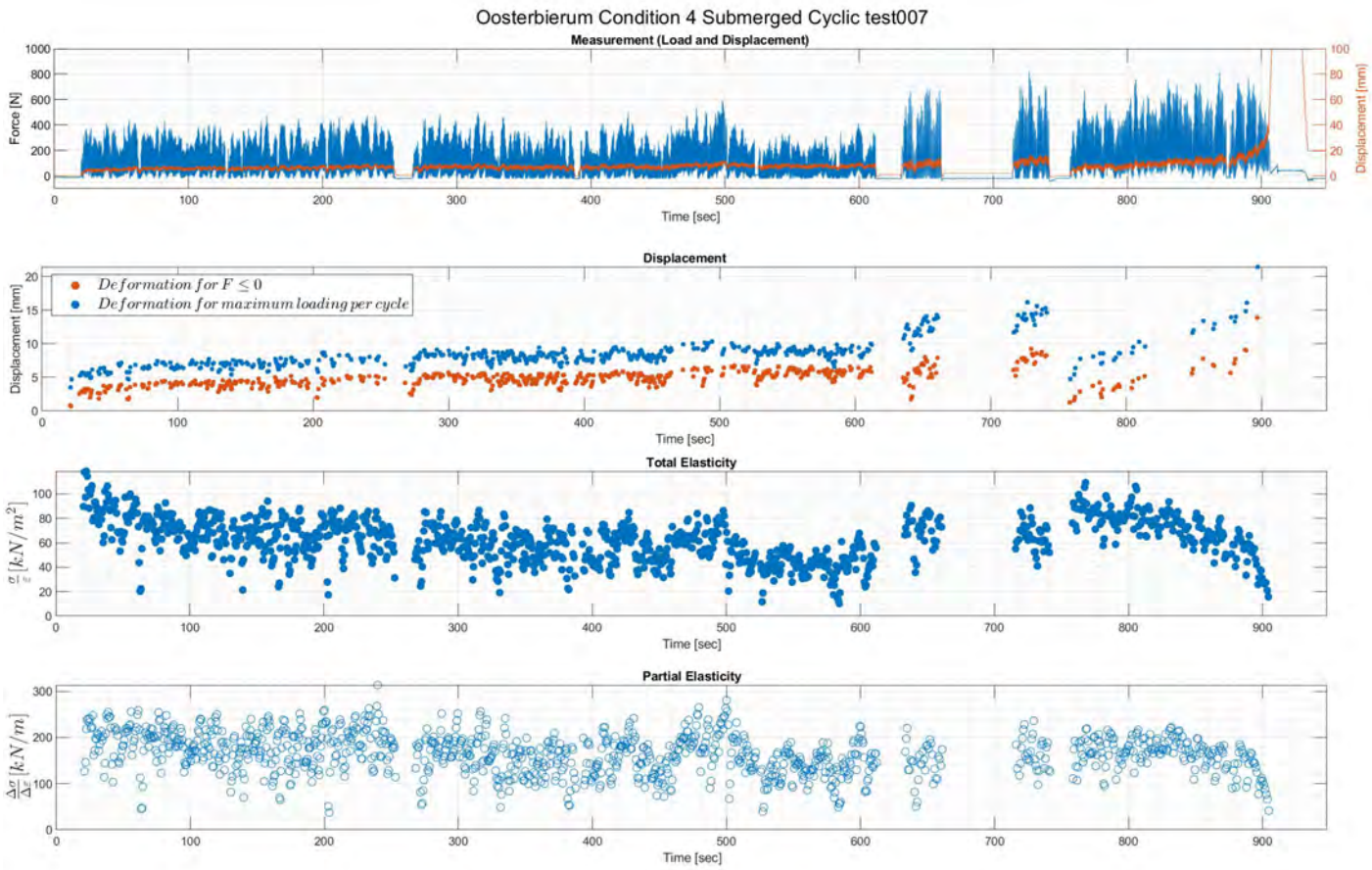


Development of displacement and elasticity are shown as function of number of cycles.

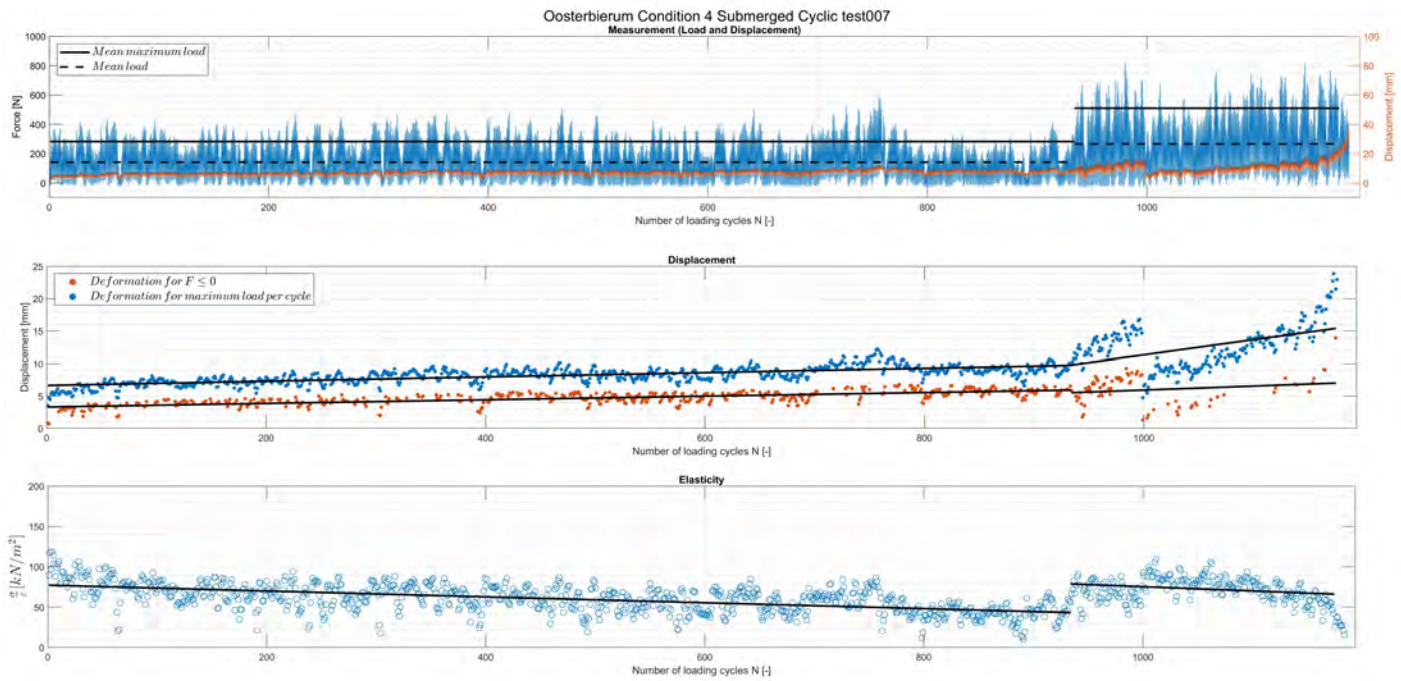
test007

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	1.42e+02	2.66e+02		2.04e+02
Mean maximum load	$[N]$	2.82e+02	5.10e+02		3.96e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	2.80e-03	6.17e-03		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	3.31e-03	2.32e-02		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	41			
Sod Height	$[cm]$	11	8	7	7.7
Root Length	$[cm]$	5	7	7	6.8
Comments					

Figure 6.6: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

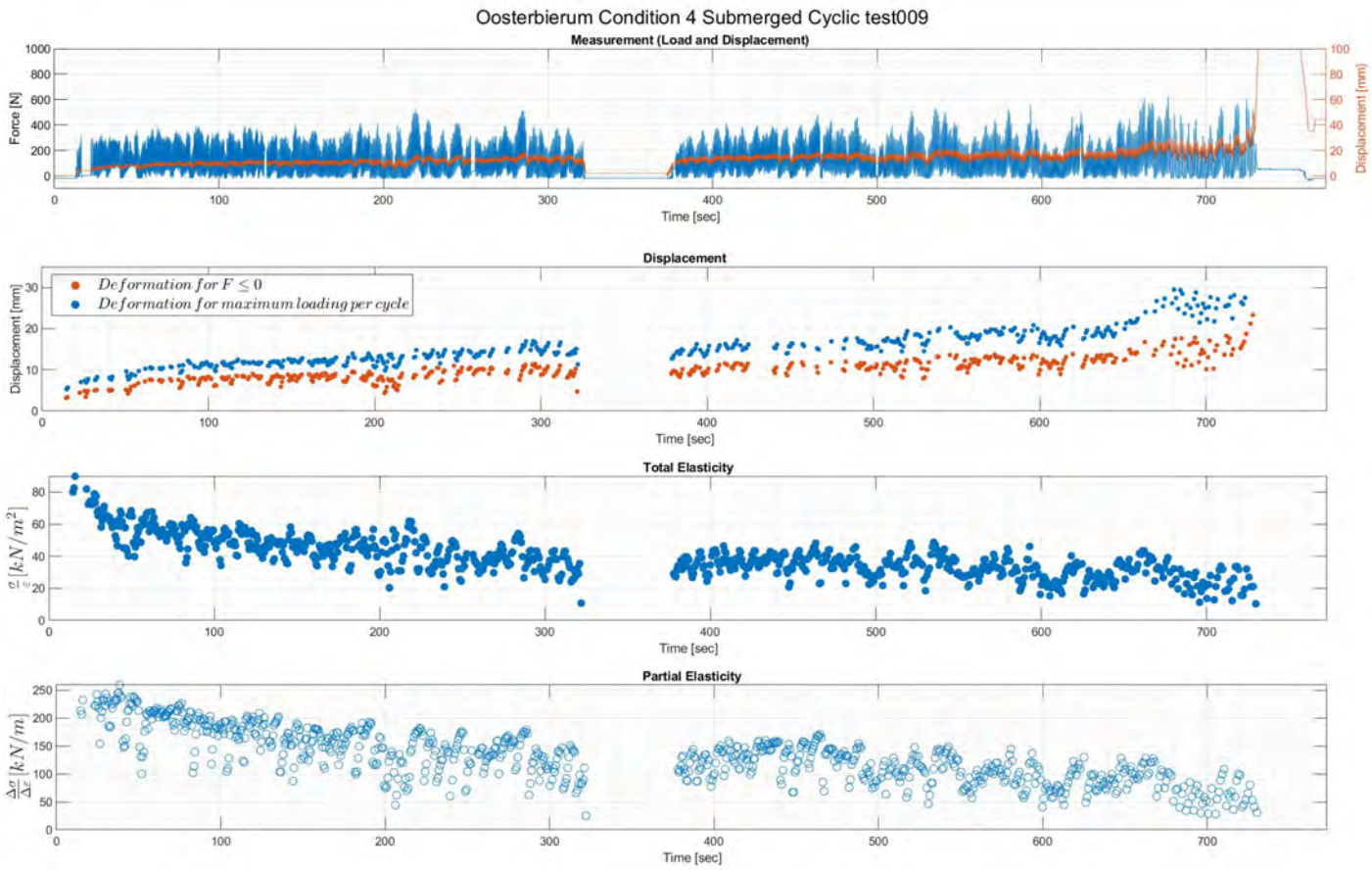


Development of displacement and elasticity are shown as function of number of cycles.

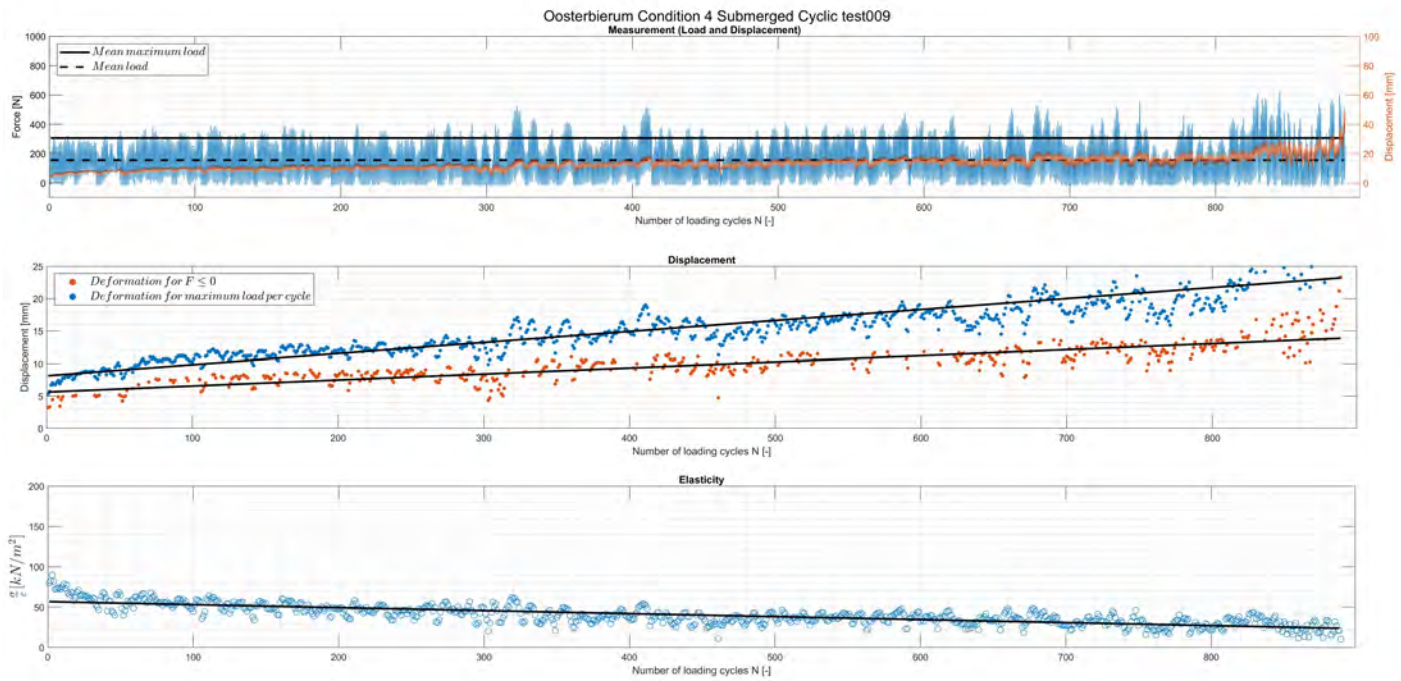
test009

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	1.53e+02	1.98e+02		1.75e+02
Mean maximum load	$[N]$	3.00e+02	3.91e+02		3.45e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	8.07e-03	5.76e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.40e-02	9.43e-02		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	50			
Sod Height	$[cm]$	10	8	8	8.6
Root Length	$[cm]$	5	7	8	6.6
Comments					

Figure 6.7: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

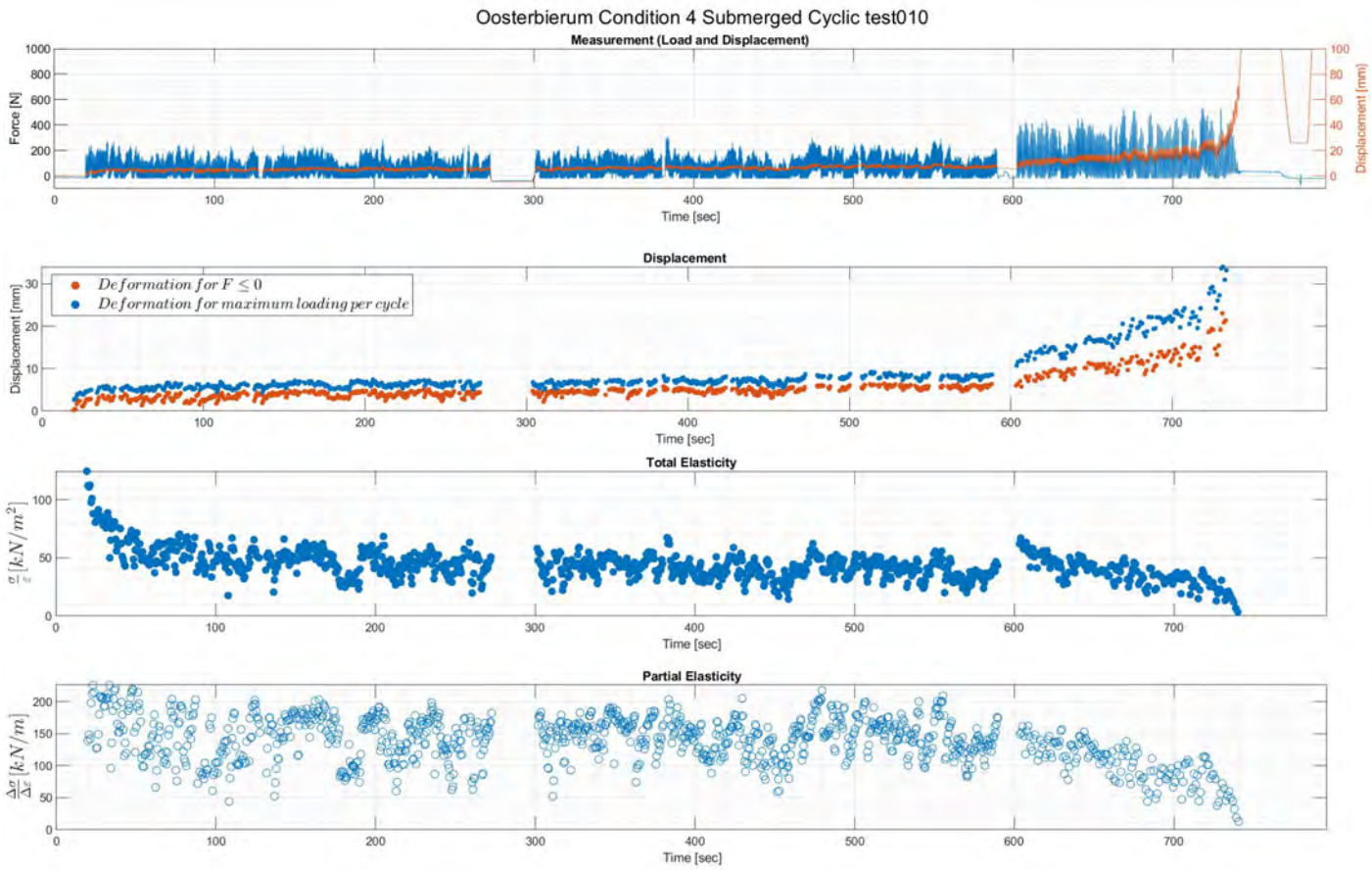


Development of displacement and elasticity are shown as function of number of cycles.

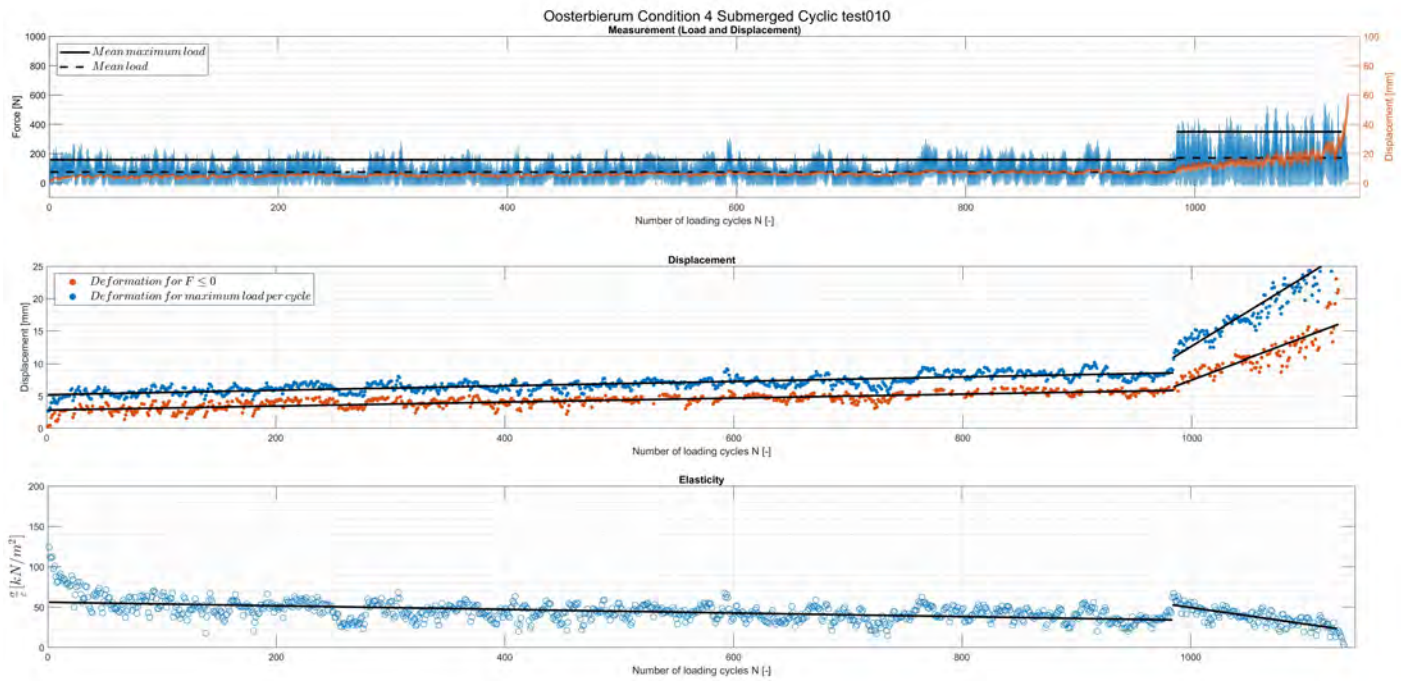
test010

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	7.45e+01	1.71e+02		1.23e+02
Mean maximum load	$[N]$	1.59e+02	3.49e+02		2.54e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	3.10e-03	6.67e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	3.45e-03	1.09e-01		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	31			
Sod Height	$[cm]$	11	8	0	8.6
Root Length	$[cm]$	8	8	0	8
Comments					

Figure 6.8: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

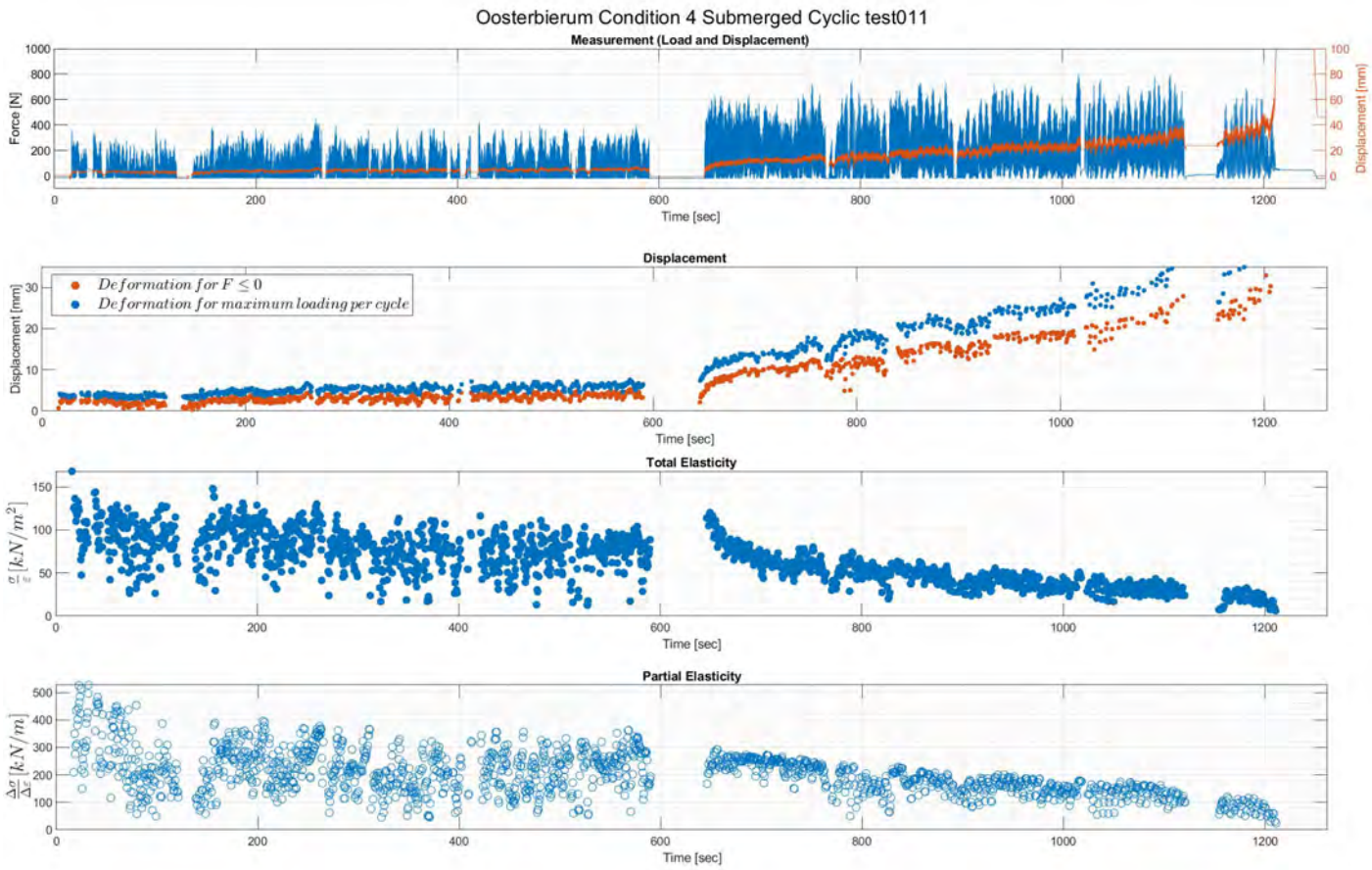


Development of displacement and elasticity are shown as function of number of cycles.

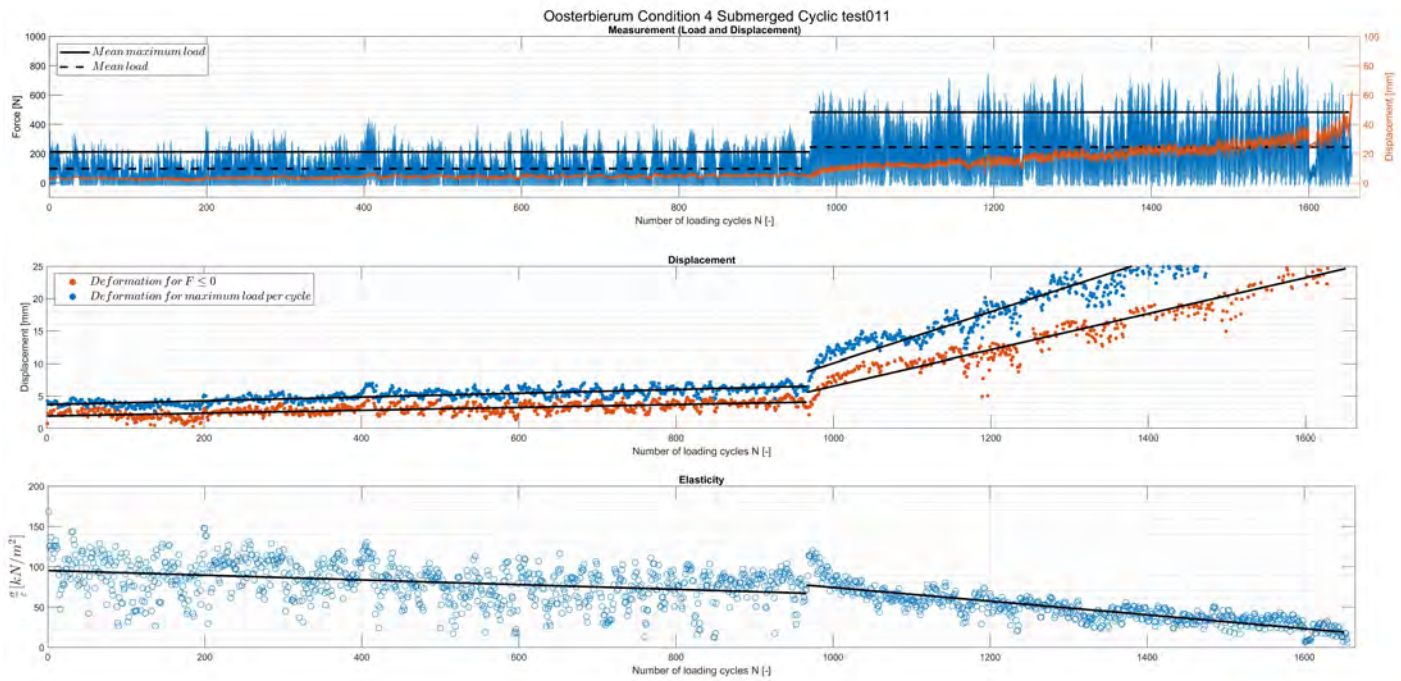
test011

		value 1	value 2	value 3	mean
Date		17-4-2019			
Mean load	$[N]$	9.73e+01	2.44e+02		1.71e+02
Mean maximum load	$[N]$	2.12e+02	4.83e+02		3.47e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	2.22e-03	2.78e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	2.92e-03	3.93e-02		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	45			
Sod Height	$[cm]$	12	8	9	8.7
Root Length	$[cm]$	5	9	9	8.6
Comments					

Figure 6.9: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

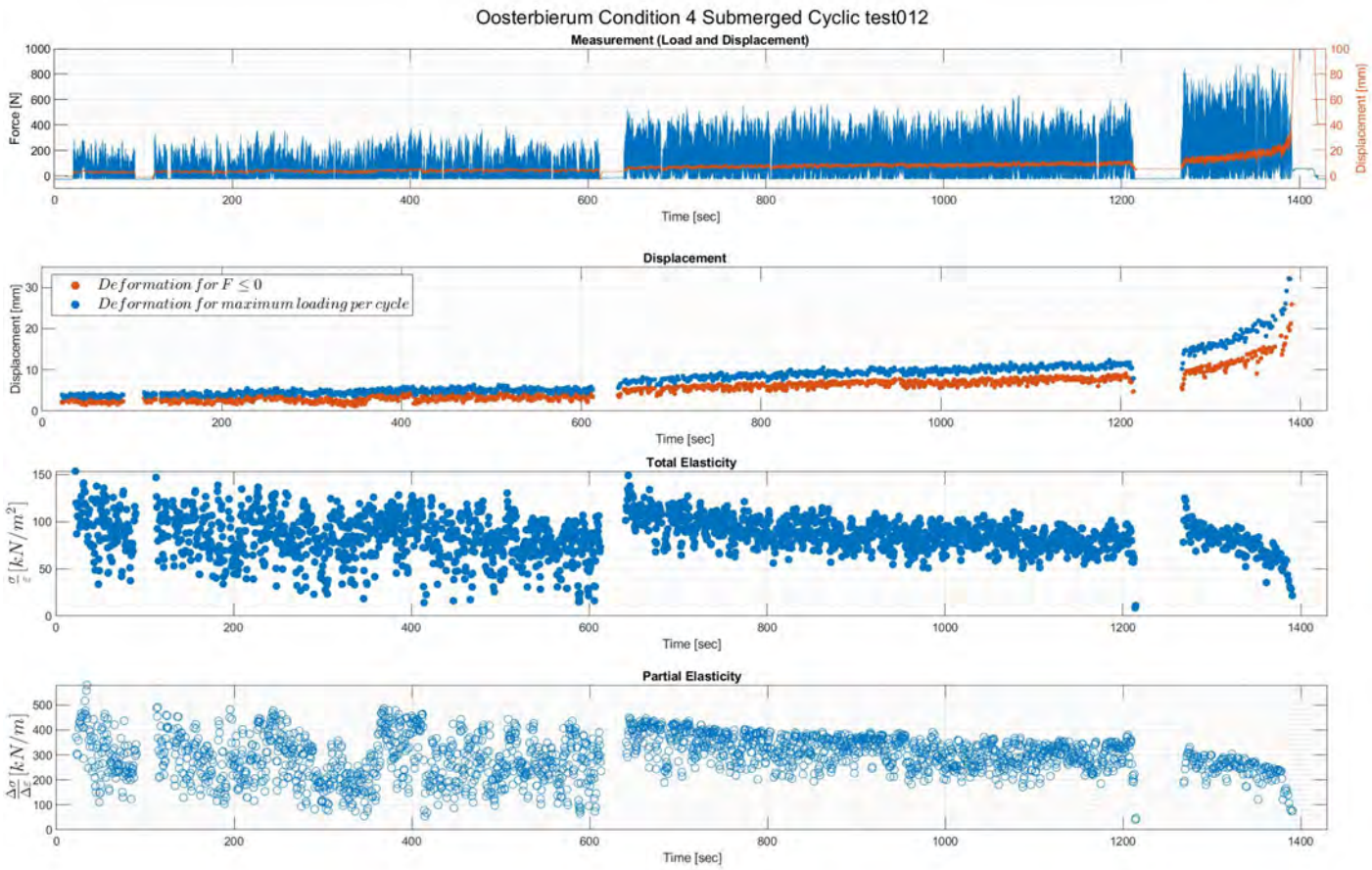


Development of displacement and elasticity are shown as function of number of cycles.

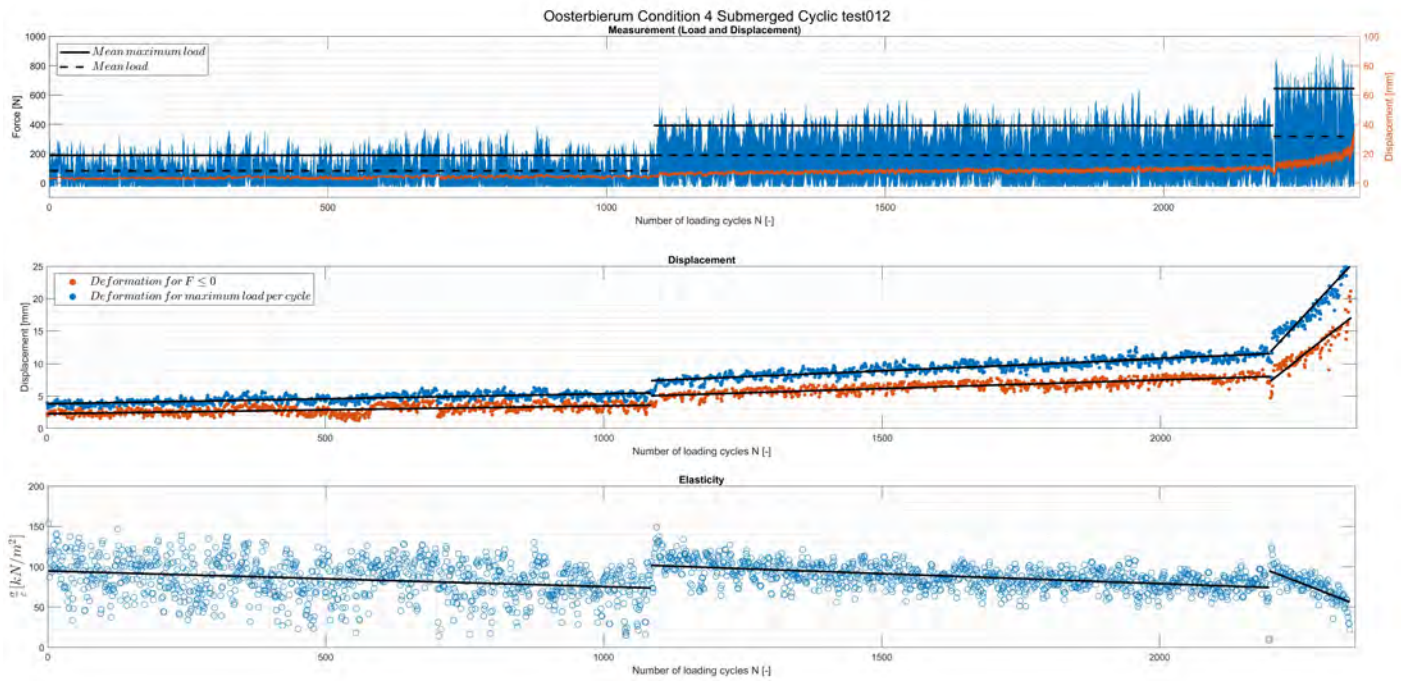
test012

		value 1	value 2	value 3	mean
Date		18-4-2019			
Mean load	$[N]$	8.26e+01	1.90e+02	3.23e+02	1.98e+02
Mean maximum load	$[N]$	1.88e+02	3.92e+02	6.54e+02	4.11e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	1.22e-03	2.58e-03	6.45e-02	
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.55e-03	3.59e-03	9.01e-02	
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	56			
Sod Height	$[cm]$	12	9	6	9.3
Root Length	$[cm]$	3	6	6	5.1
Comments					

Figure 6.10: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



Development of displacement and elasticity are shown as function of number of cycles.

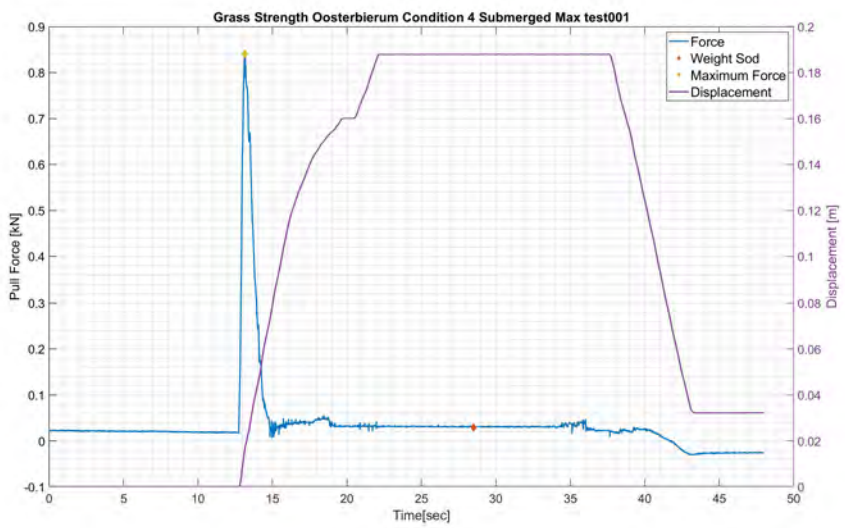
Submerged Condition 4 Max

	F max $[N]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test001	834	3.1	21	7.8	6.8
test003	780	2.7	21	6.5	8.0
test004	795	3.2	21	8.0	8.0
test005	1045	3.9	21	8.4	4.4
test006	926	2.8	21	7.9	7.4
test007	929	1.0	21	6.6	7.8
test008	760	3.5	21	8.1	7.0
test009	799	5.2	21	6.5	6.2
test010	855	2.5	21	6.3	5.7
test011	1148	5.0	21	7.1	5.4
test012	1213	3.7	21	7.0	6.4
Mean	955	3.1	21	7.3	6.6
Median	926	3.2	21	7	7
75th percentile	1148	3.8	21	8	8
25th percentile	798	2.6	21	7	6

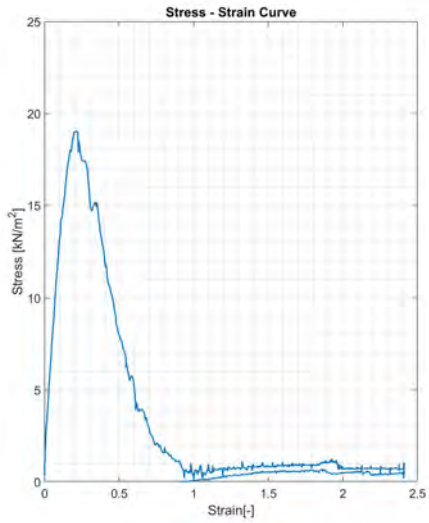
test001

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	826			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	31			
Sod Height	$[cm]$	9	6	0	7.8
Root Length	$[cm]$	6	8	0	6.8
Comments					

Figure 7.1: Pictures of tested grass sod.



Measurement of load and displacement

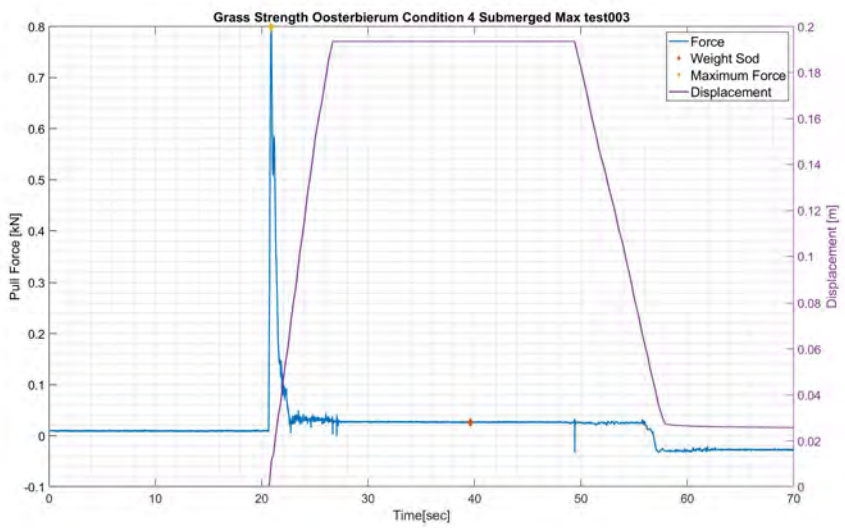


Stress - Strain relation.

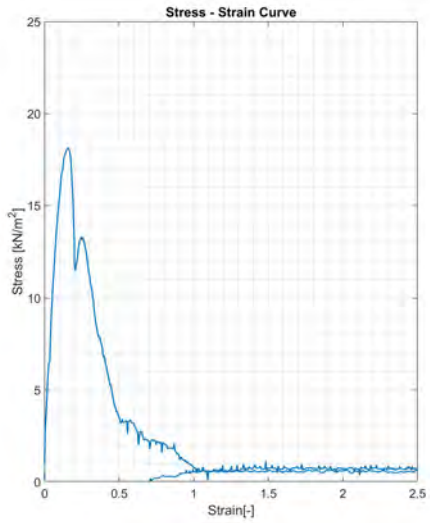
test003

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	775			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	27			
Sod Height	$[cm]$	7	6	0	6.5
Root Length	$[cm]$	8	8	0	8
Comments					

Figure 7.2: Pictures of tested grass sod.



Measurement of load and displacement

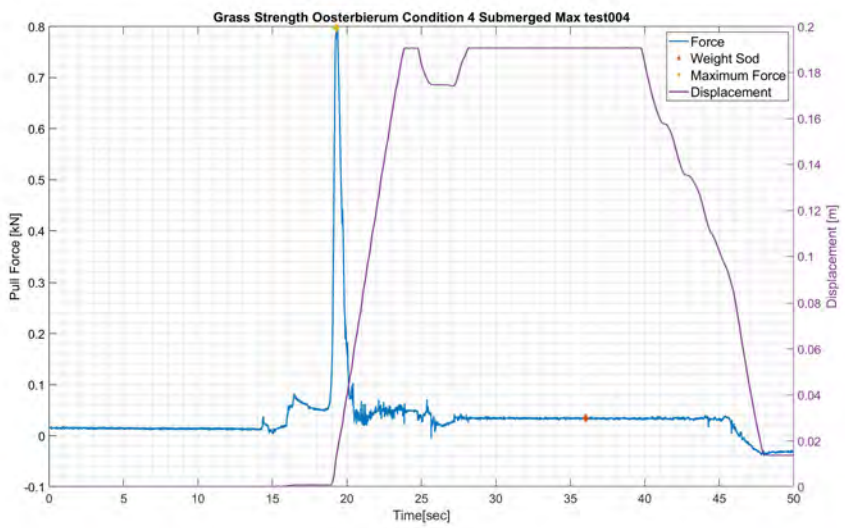


Stress - Strain relation.

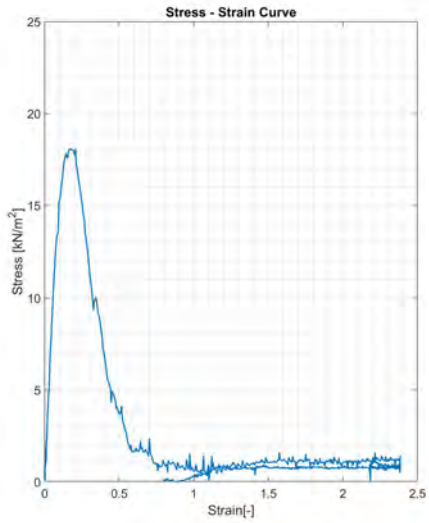
test004

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	793			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	32			
Sod Height	$[cm]$	9	7	8	8
Root Length	$[cm]$	8	8	8	8
Comments					

Figure 7.3: Pictures of tested grass sod.



Measurement of load and displacement

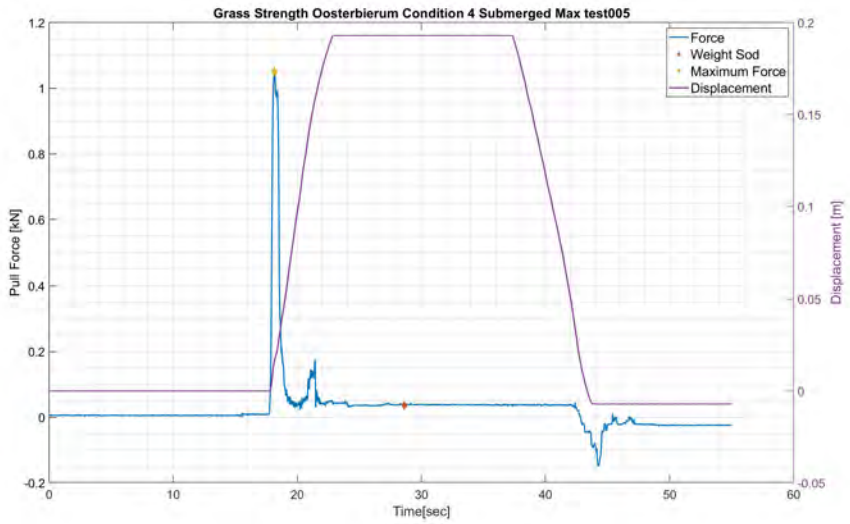


Stress - Strain relation.

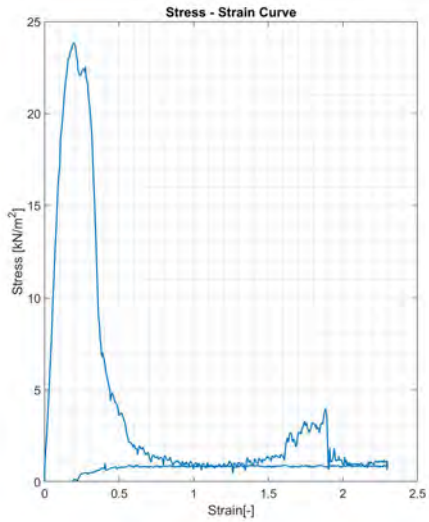
test005

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	1043			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	39			
Sod Height	$[cm]$	10	8	8	8.4
Root Length	$[cm]$	2	4	8	4.4
Comments					

Figure 7.4: Pictures of tested grass sod.



Measurement of load and displacement

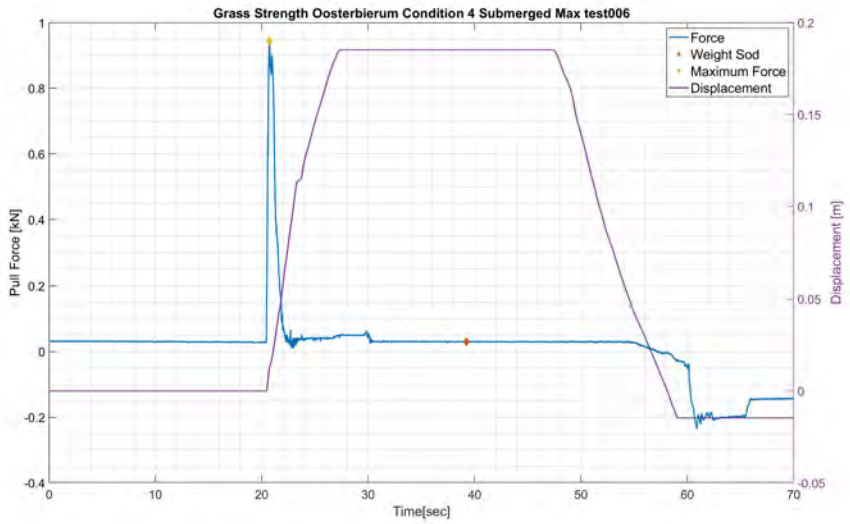


Stress - Strain relation.

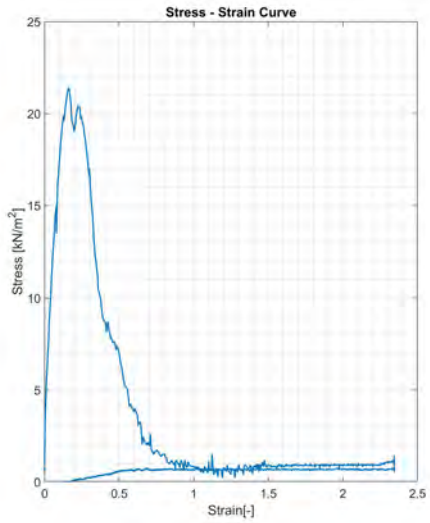
test006

		value 1	value 2	value 3	mean
Date		20-3-2019			
Maximum load	$[N]$	924			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	28			
Sod Height	$[cm]$	9	7	8	7.9
Root Length	$[cm]$	5	8	8	7.4
Comments					

Figure 7.5: Pictures of tested grass sod.



Measurement of load and displacement

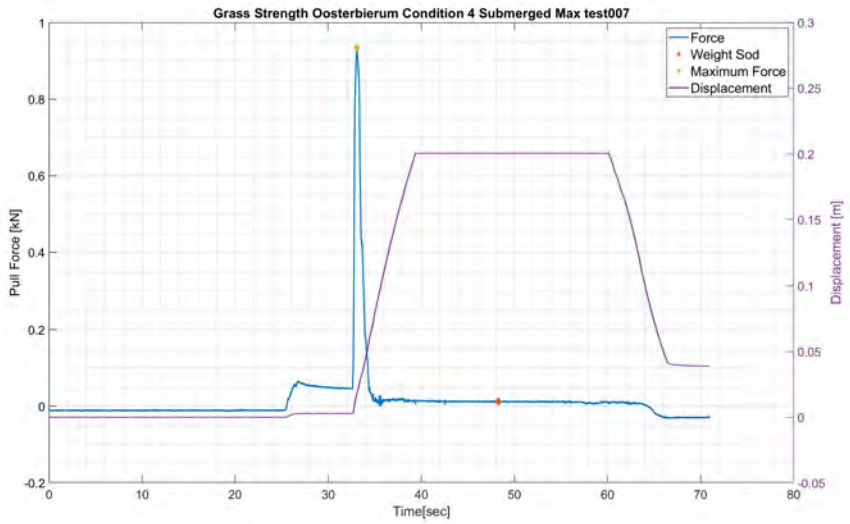


Stress - Strain relation.

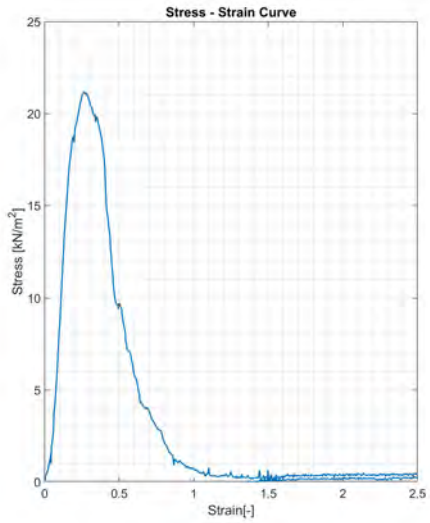
test007

		value 1	value 2	value 3	mean
Date		20-3-2019			
Maximum load	$[N]$	929			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	10			
Sod Height	$[cm]$	8	6	8	6.6
Root Length	$[cm]$	6	8	8	7.8
Comments					

Figure 7.6: Pictures of tested grass sod.



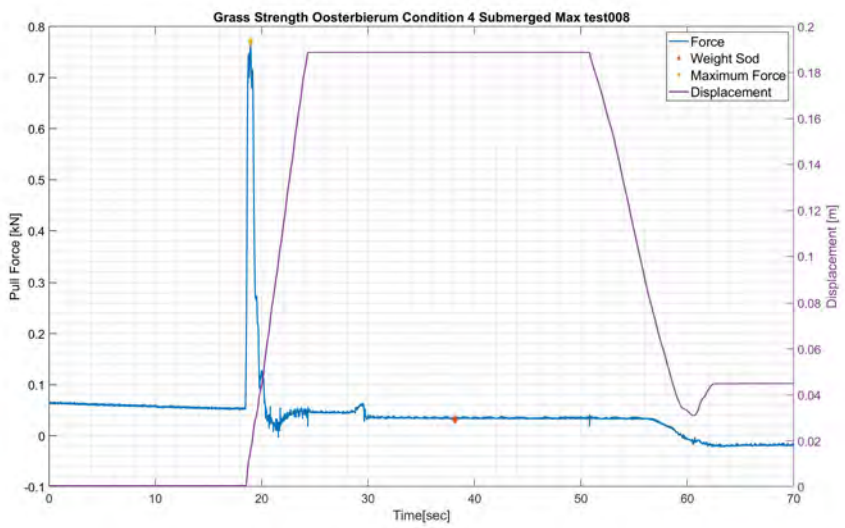
Measurement of load and displacement



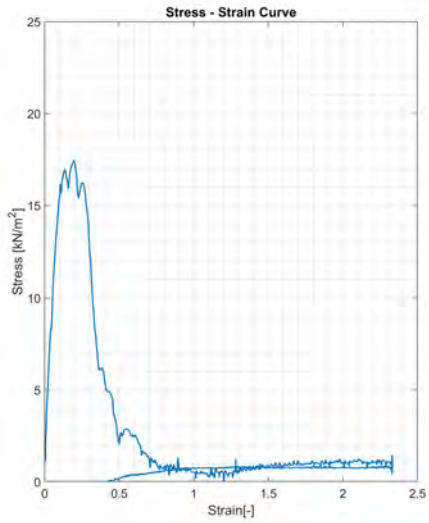
Stress - Strain relation.

test008

		value 1	value 2	value 3	mean
Date		20-3-2019			
Maximum load	$[N]$	760			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	35			
Sod Height	$[cm]$	9	8	0	8.1
Root Length	$[cm]$	7	7	0	7
Comments					



Measurement of load and displacement

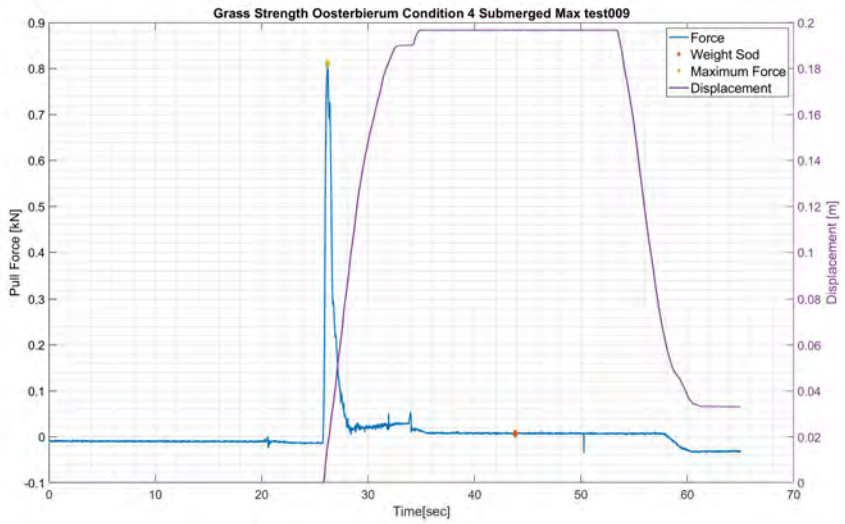


Stress - Strain relation.

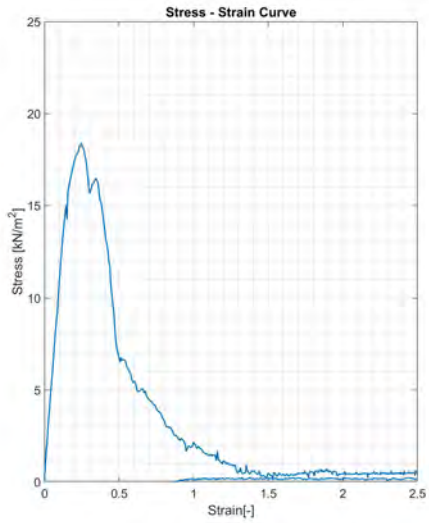
test009

		value 1	value 2	value 3	mean
Date		20-3-2019			
Maximum load	$[N]$	799			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	52			
Sod Height	$[cm]$	7	6	7	6.5
Root Length	$[cm]$	6	6	7	6.2
Comments					

Figure 7.7: Pictures of tested grass sod.



Measurement of load and displacement

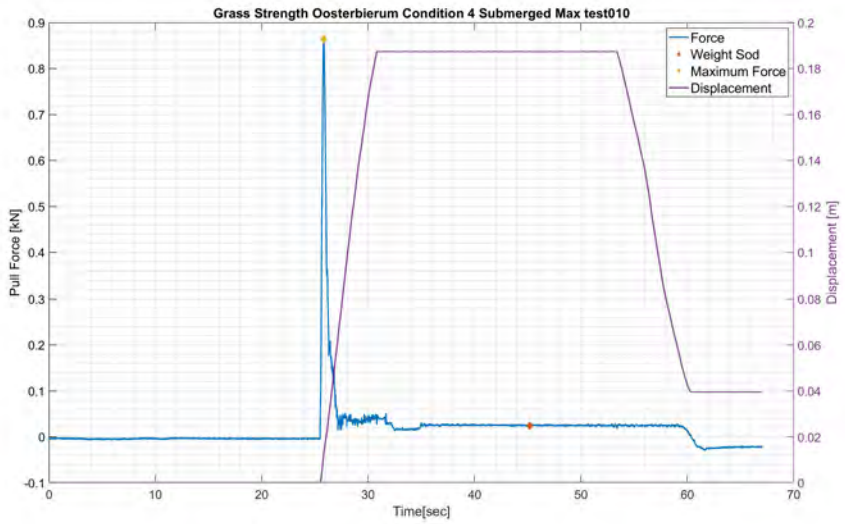


Stress - Strain relation.

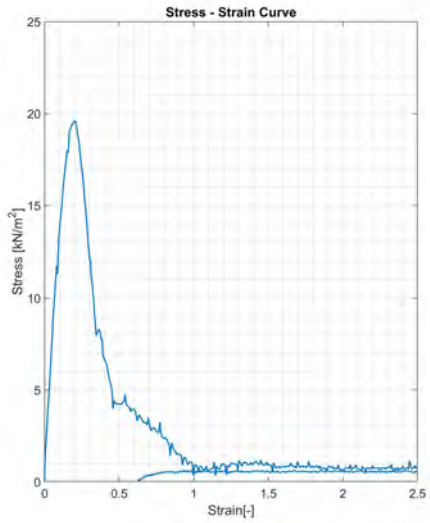
test010

		value 1	value 2	value 3	mean
Date		20-3-2019			
Maximum load	$[N]$	851			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	25			
Sod Height	$[cm]$	7	6	0	6.3
Root Length	$[cm]$	5	6	0	5.7
Comments					

Figure 7.8: Pictures of tested grass sod.



Measurement of load and displacement

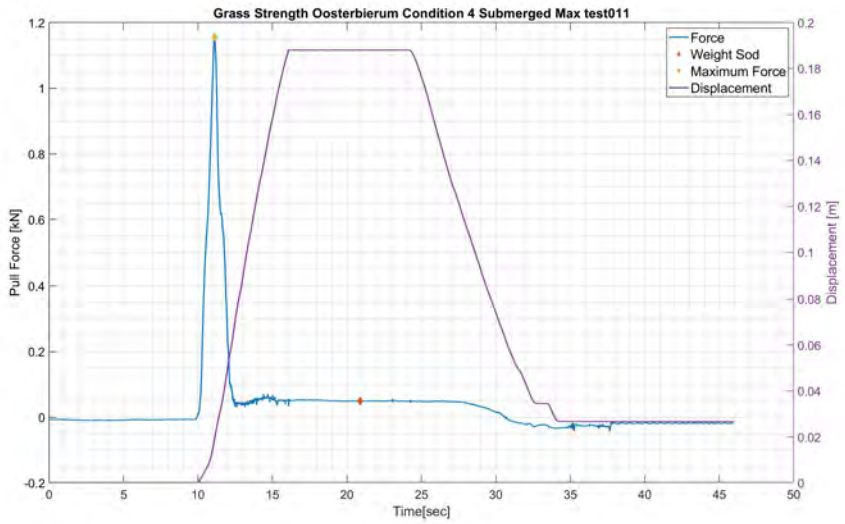


Stress - Strain relation.

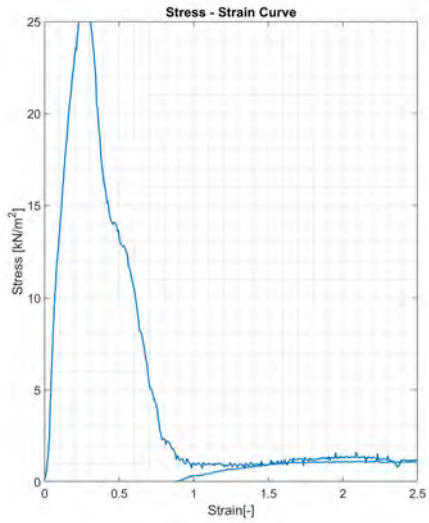
test011

		value 1	value 2	value 3	mean
Date		15-4-2019			
Maximum load	$[N]$	1146			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	50			
Sod Height	$[cm]$	9	8	4	7.1
Root Length	$[cm]$	6	6	4	5.4
Comments					

Figure 7.9: Pictures of tested grass sod.



Measurement of load and displacement

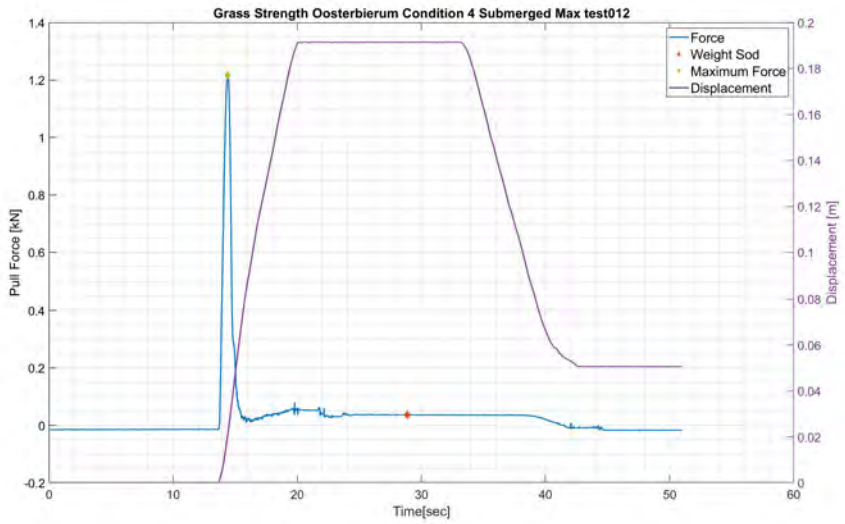


Stress - Strain relation.

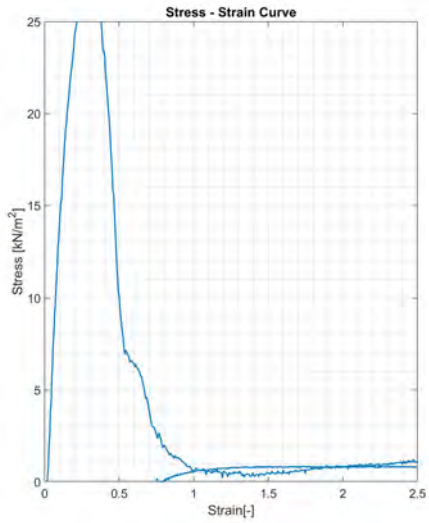
test012

		value 1	value 2	value 3	mean
Date		18-4-2019			
Maximum load	$[N]$	1210			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	37			
Sod Height	$[cm]$	9	8	6	7
Root Length	$[cm]$	6	8	6	6.4
Comments					

Figure 7.10: Pictures of tested grass sod.



Measurement of load and displacement



Stress - Strain relation.

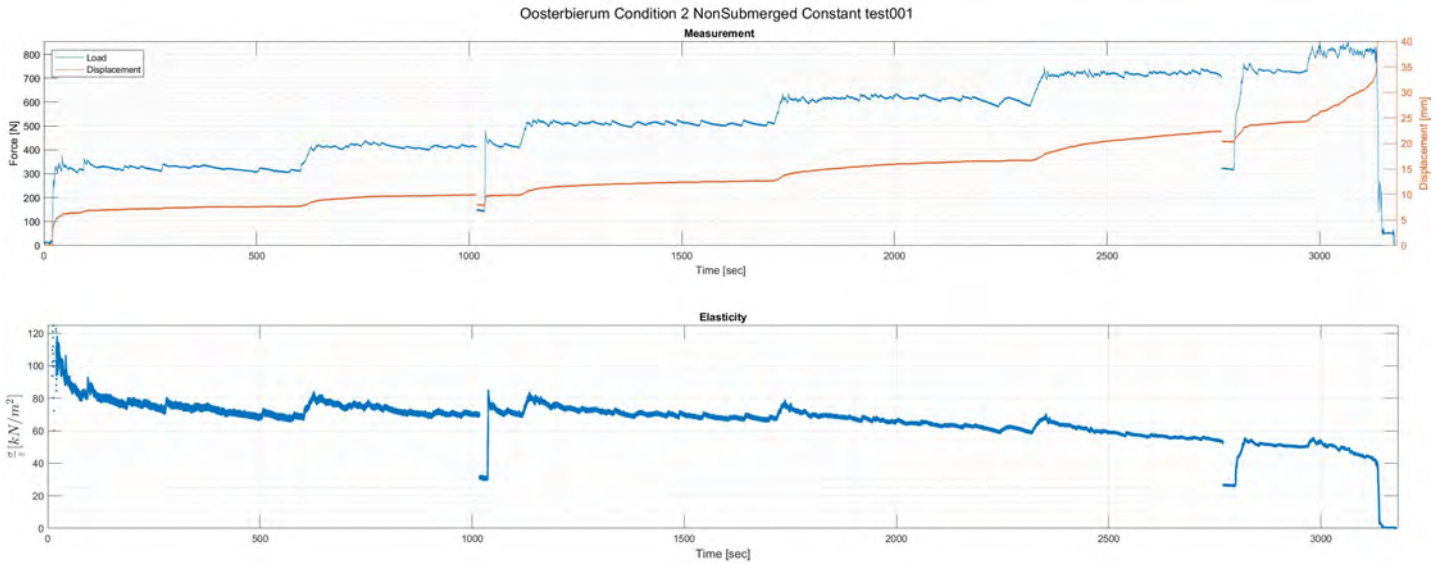
Submerged Condition 2 Constant

	Time to reach 80% of displacement $[sec]$	$E\,[kN/m^2]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test007	6	95.24	5.1	28.0	9.4	1.2
test005	3	76.27	5.3	32.0	8.6	3.6
test004	6	114.24	3.8	28.0	11.0	2.0
test003	28	184.61	3.9	25.0	10.7	2.0
test002	17	40.87	NaN	28.0	11.4	2.2
test001	22	67.55	4.8	21.0	8.6	6.0
mean	14	96.46	4.6	27.0	9.9	2.8
median	11	85.75	4.8	28.0	10.0	2.1
75th percentile	22	114.24	5.1	28.0	11.0	3.6
25th percentile	6	67.55	3.9	25.0	8.6	2.0

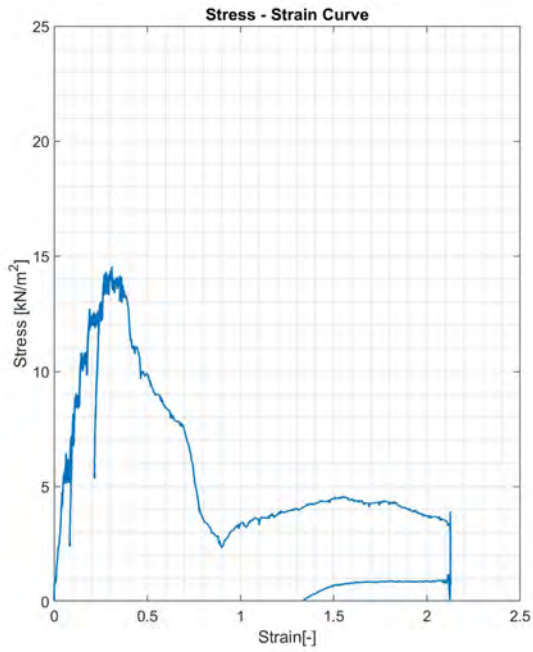
test001

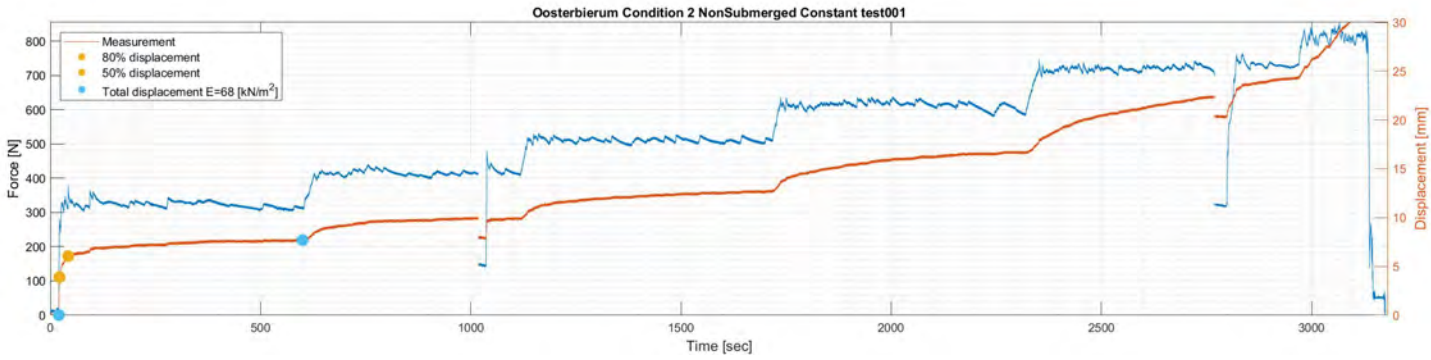
		value 1	value 2	value 3	mean
Date		14-3-2019			
E	$[kN/m^2]$	67.55			
Time to reach 80% of displacement	$[sec]$	22			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	51			
Sod Height	$[cm]$	13	11	2	9.4
Root Length	$[cm]$	1	1	2	1.2
Comments					

Figure 8.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



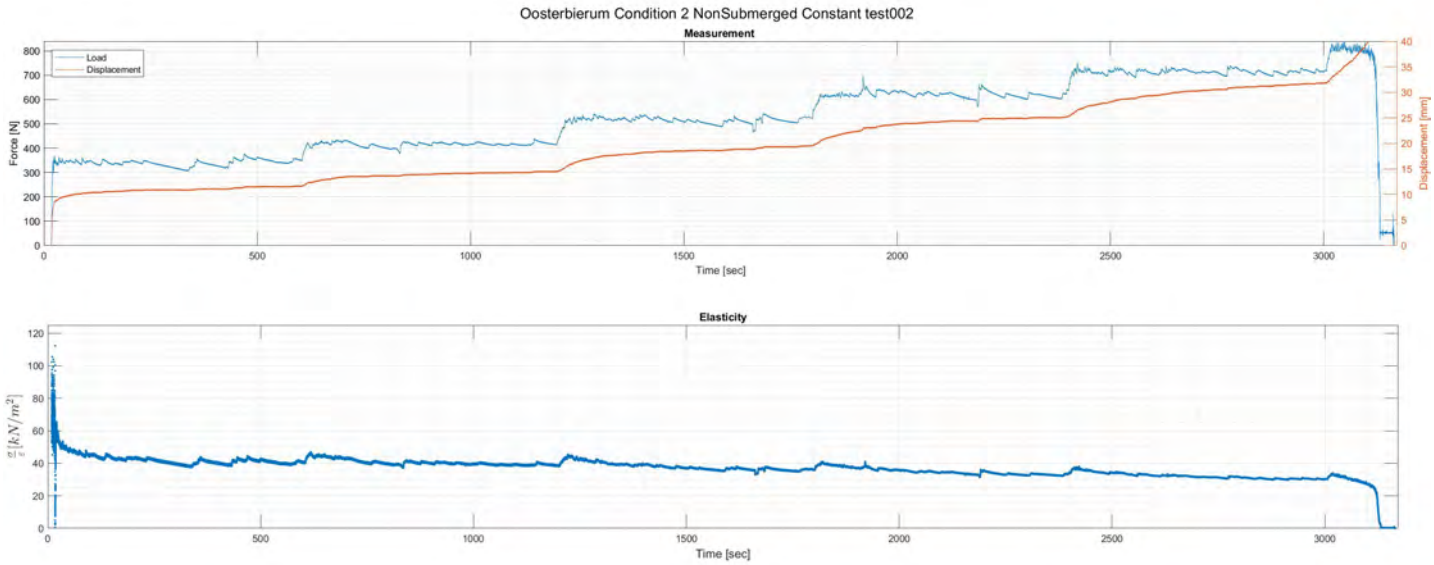


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

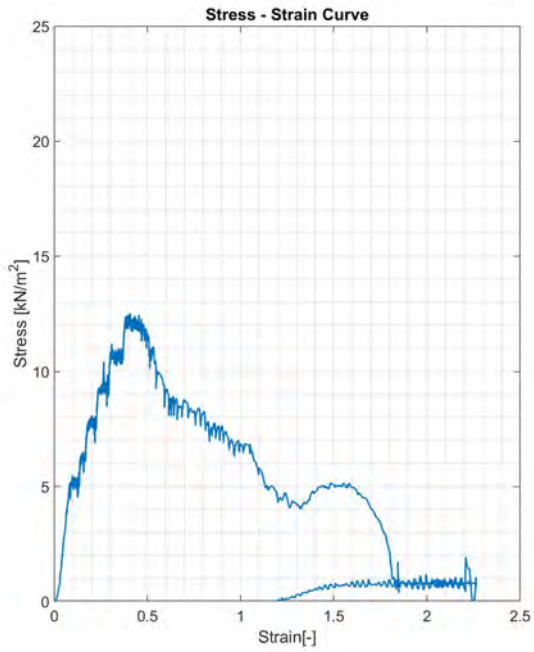
test002

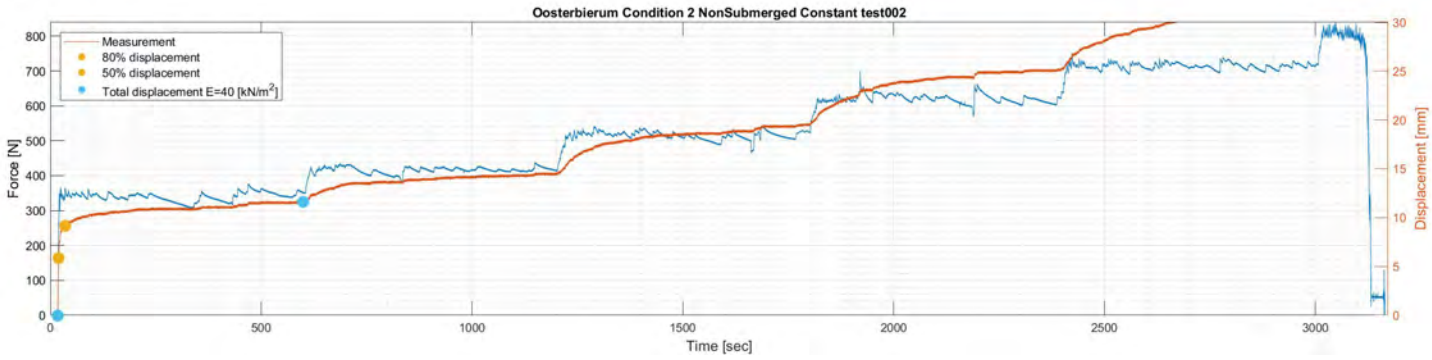
		value 1	value 2	value 3	mean
Date		15-3-2019			
E	$[kN/m^2]$	40.87			
Time to reach 80% of displacement	$[sec]$	17			
Width Sod	$[cm]$	32			
Weight Sod	$[N]$	53			
Sod Height	$[cm]$	12	10	4	8.6
Root Length	$[cm]$	2	4	4	3.6
Comments					

Figure 8.2: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



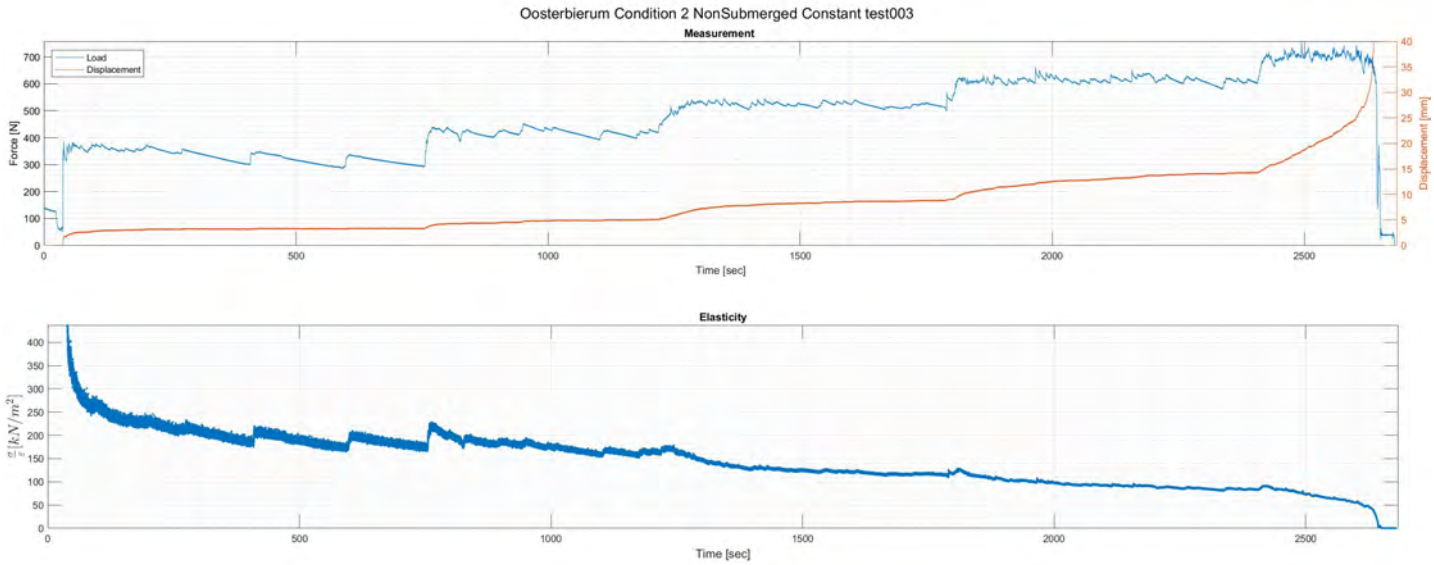


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

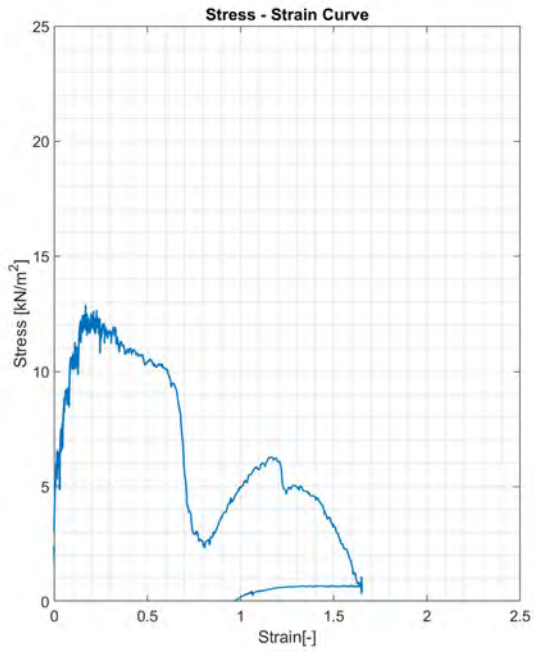
test003

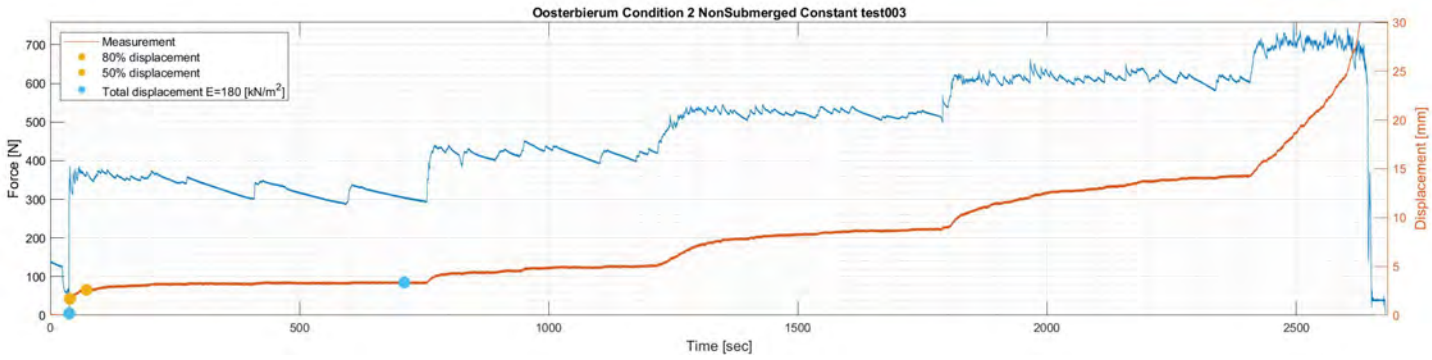
		value 1	value 2	value 3	mean
Date		18-3-2019			
E	$[kN/m^2]$	184.61			
Time to reach 80% of displacement	$[sec]$	28			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	38			
Sod Height	$[cm]$	11	0	0	11
Root Length	$[cm]$	2	0	0	2
Comments					

Figure 8.3: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



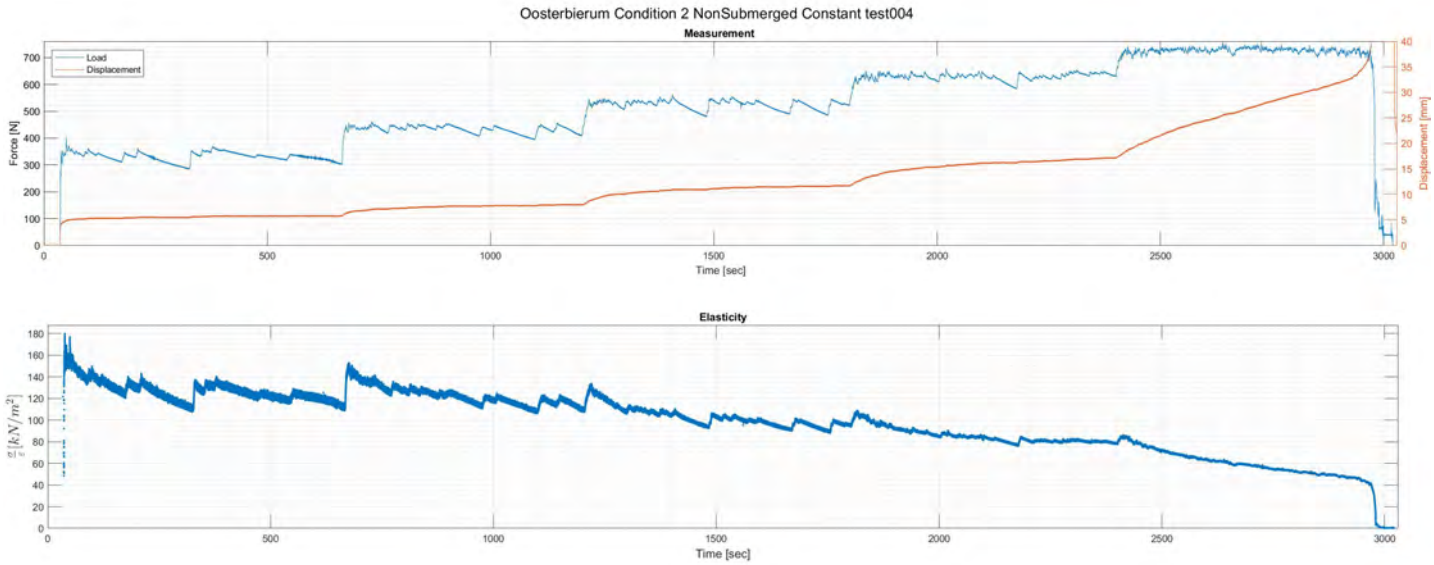


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

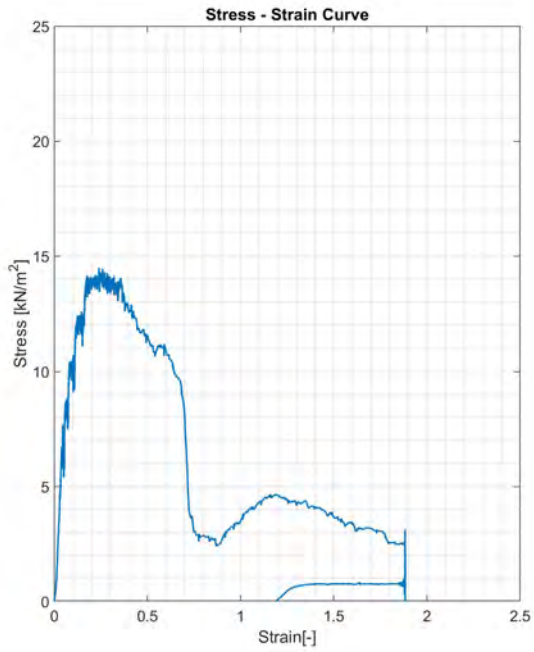
test004

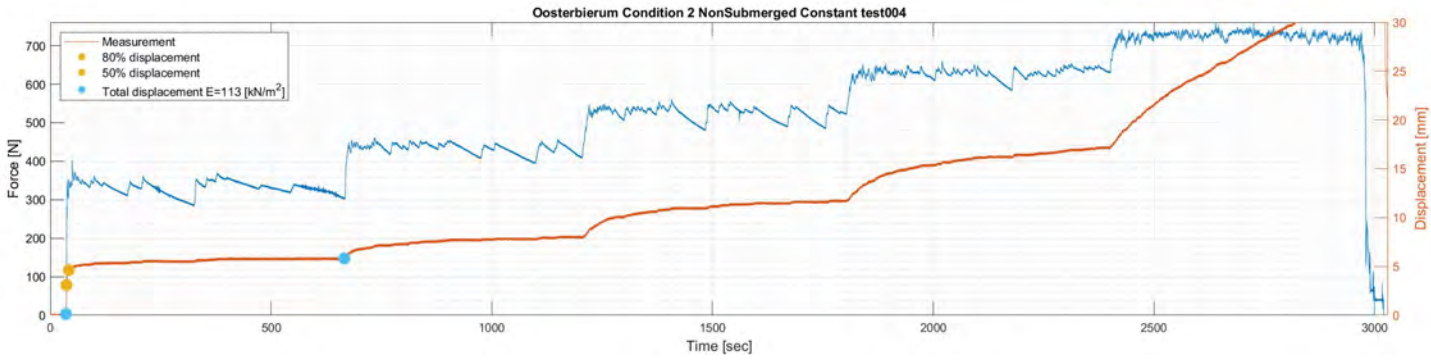
		value 1	value 2	value 3	mean
Date		18-3-2019			
E	$[kN/m^2]$	114.24			
Time to reach 80% of displacement	$[sec]$	6			
Width Sod	$[cm]$	25			
Weight Sod	$[N]$	39			
Sod Height	$[cm]$	12.5	7	5	10.7
Root Length	$[cm]$	1	4	5	2
Comments					

Figure 8.4: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



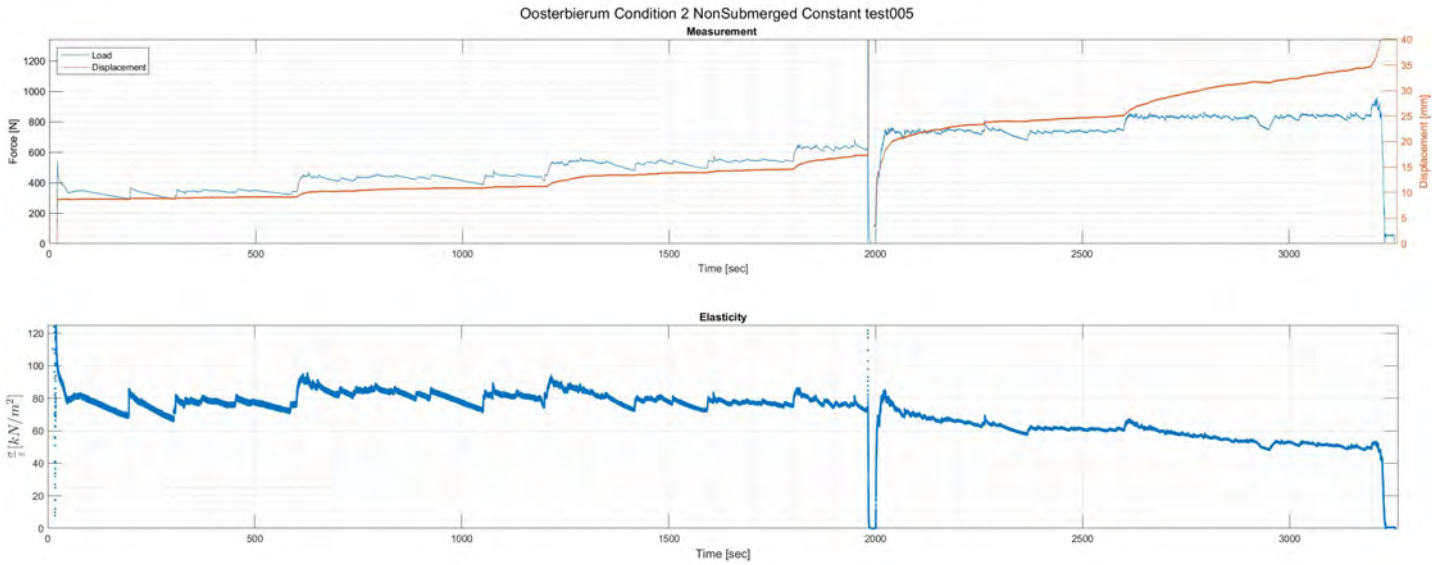


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

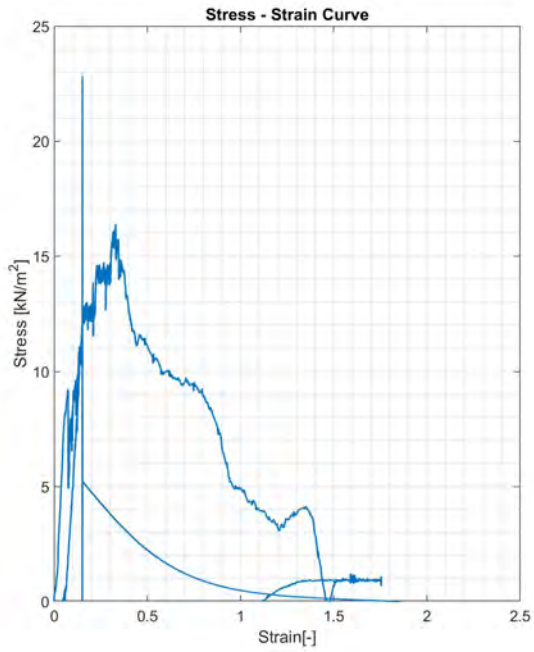
test005

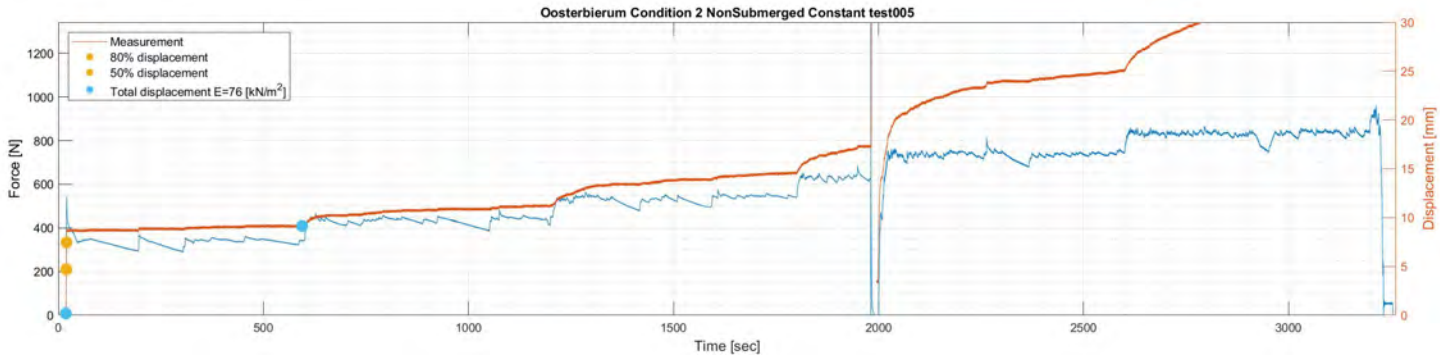
		value 1	value 2	value 3	mean
Date		18-3-2019			
E	$[kN/m^2]$	76.27			
Time to reach 80% of displacement	$[sec]$	3			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	NaN			
Sod Height	$[cm]$	13.5	10	0	11.4
Root Length	$[cm]$	1	3	0	2.2
Comments					

Figure 8.5: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



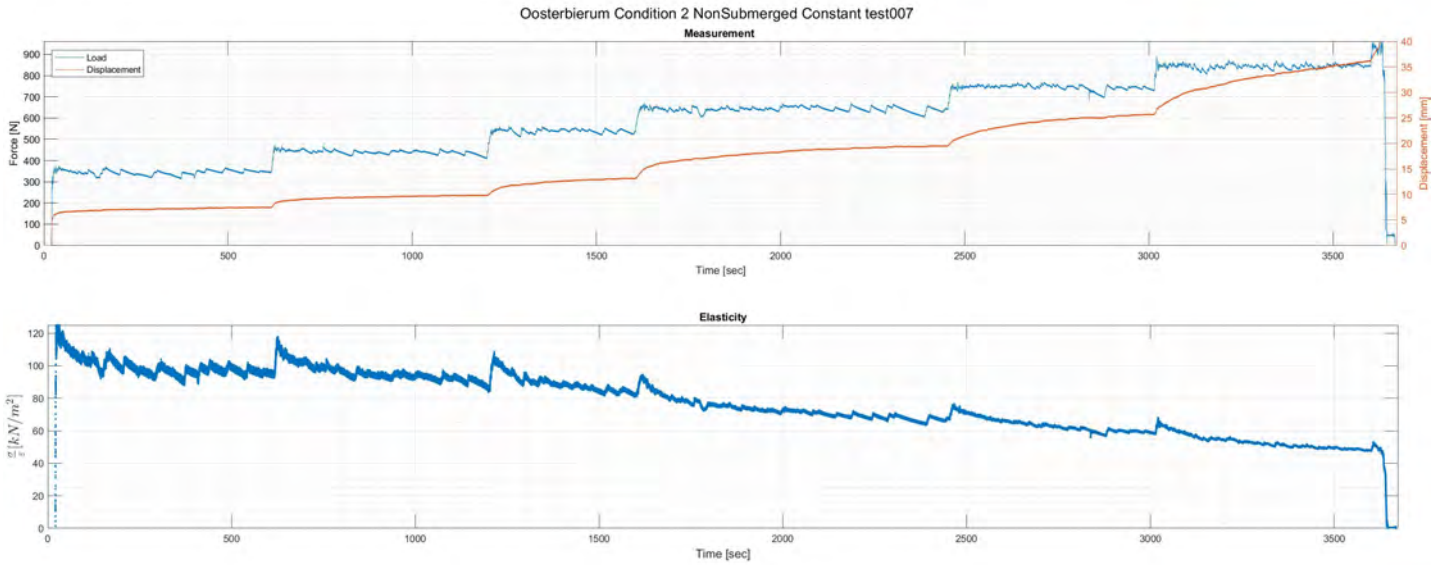


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

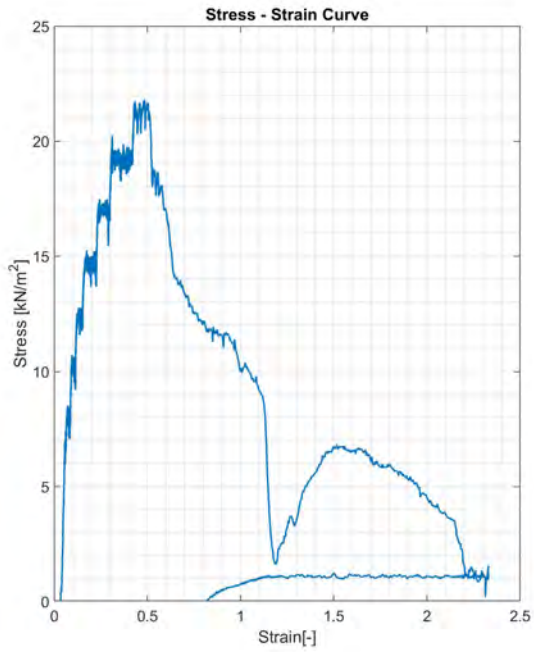
test007

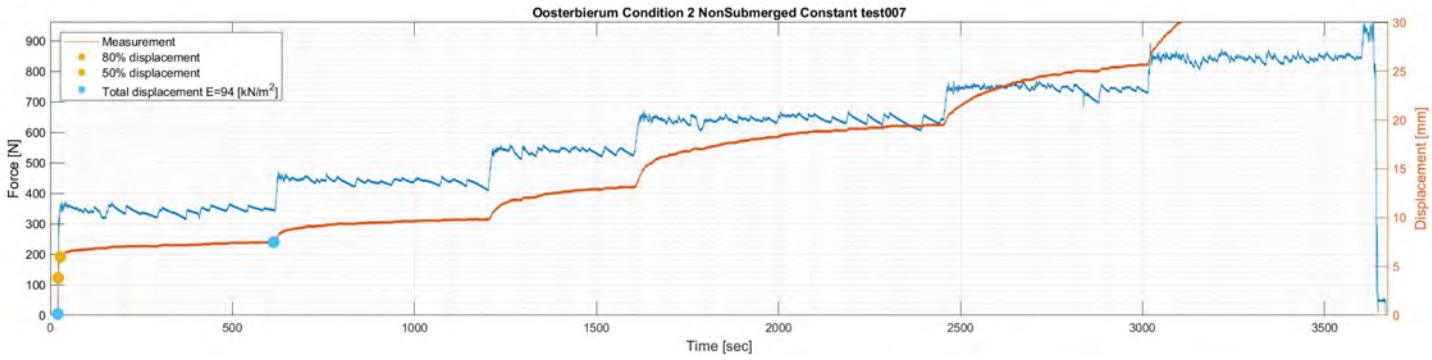
		value 1	value 2	value 3	mean
Date		21-3-2019			
E	$[kN/m^2]$	95.24			
Time to reach 80% of displacement	$[sec]$	6			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	48			
Sod Height	$[cm]$	9	8	0	8.6
Root Length	$[cm]$	6	6	0	6
Comments					

Figure 8.6: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.





Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

NonSubmerged Condition 2 Cyclic

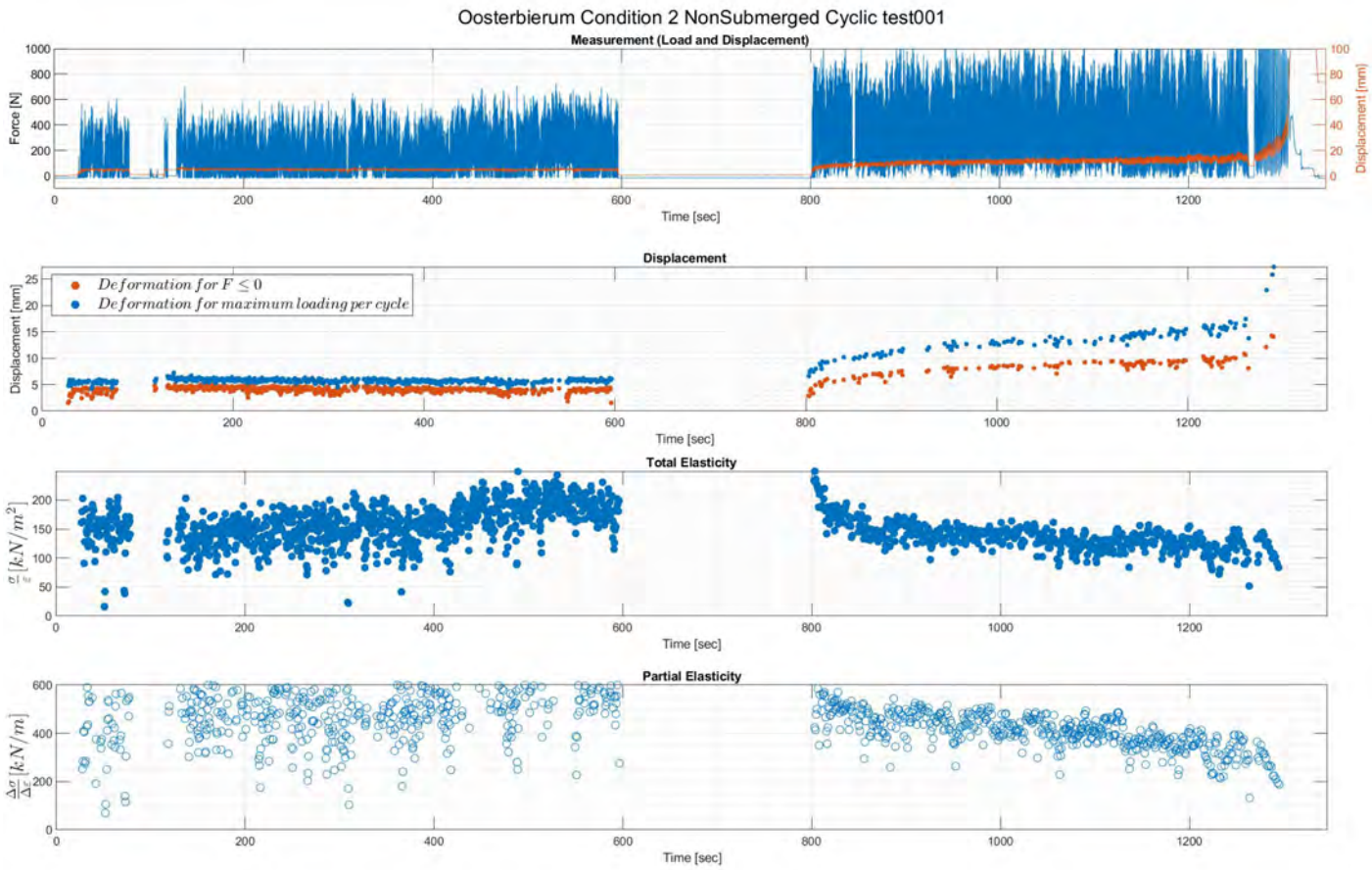
	Growth rate $\frac{\Delta U}{n}$ $[mm]$						Load					
	Plastic deformation			Maximum deformation			Mean			Mean maximum		
Load block	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800
test001	-3.00e-04	8.38e-03	4.17e-01	-1.16e-04	1.34e-02	8.28e-01	2.20e+02	4.44e+02	6.46e+02	4.41e+02	8.55e+02	1.23e+03
mean	-3.00e-04	8.38e-03	4.17e-01	-1.16e-04	1.34e-02	8.28e-01	2.20e+02	4.44e+02	6.46e+02	4.41e+02	8.55e+02	1.23e+03
median	-3.00e-04	8.38e-03	4.17e-01	-1.16e-04	1.34e-02	8.28e-01	2.20e+02	4.44e+02	6.46e+02	4.41e+02	8.55e+02	1.23e+03
75th percentile	-3.00e-04	8.38e-03	4.17e-01	-1.16e-04	1.34e-02	8.28e-01	2.20e+02	4.44e+02	6.46e+02	4.41e+02	8.55e+02	1.23e+03
25th percentile	-3.00e-04	8.38e-03	4.17e-01	-1.16e-04	1.34e-02	8.28e-01	2.20e+02	4.44e+02	6.46e+02	4.41e+02	8.55e+02	1.23e+03

	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test001	5.9	25.0	11.0	1.0
Mean	5.9	25	11	1
Median	5.9	25	11	1
75th percentile	5.9	25	11	1
25th percentile	5.9	25	11	1

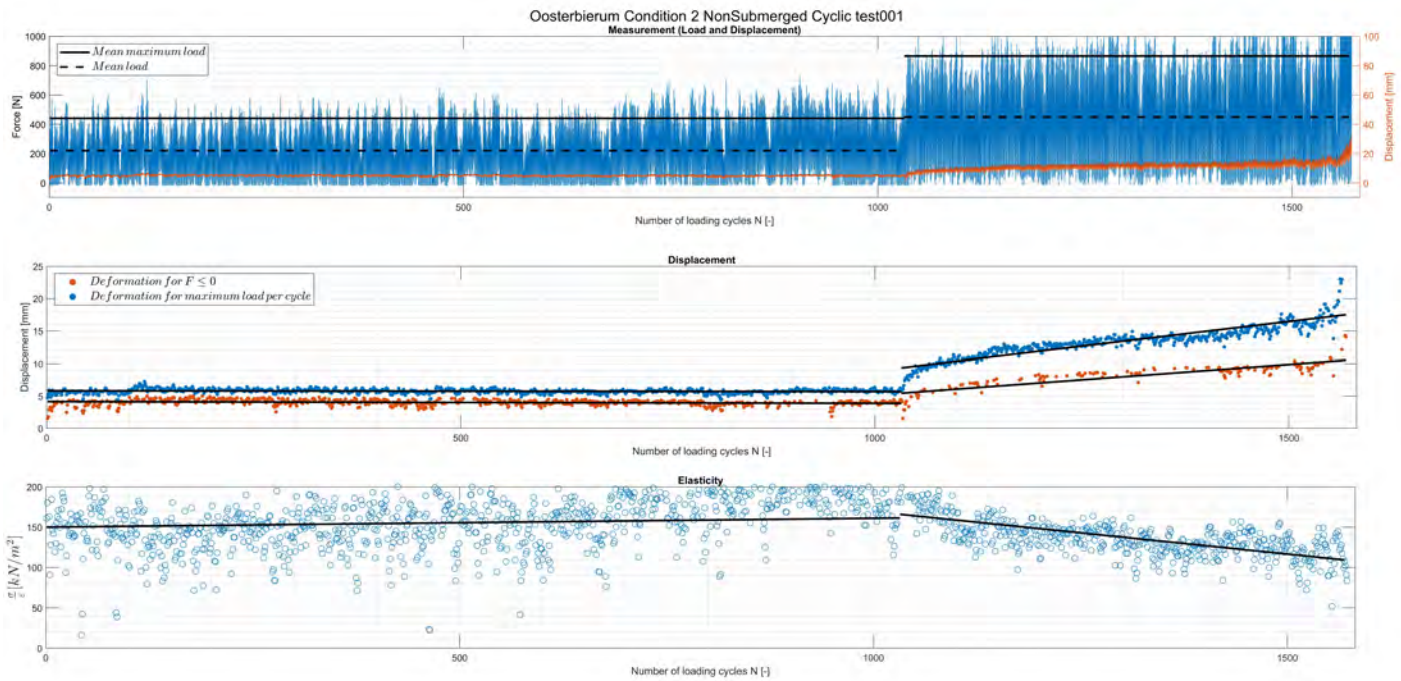
test001

		value 1	value 2	value 3	mean
Date		18-4-2019			
Mean load	$[N]$	2.20e+02	4.44e+02	6.46e+02	4.37e+02
Mean maximum load	$[N]$	4.41e+02	8.55e+02	1.23e+03	8.41e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	-3.00e-04	8.38e-03	4.17e-01	
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	-1.16e-04	1.34e-02	8.28e-01	
Width Sod	$[cm]$	25			
Weight Sod	$[N]$	59			
Sod Height	$[cm]$	12	7	0	11
Root Length	$[cm]$	1	1	0	1
Comments					

Figure 9.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



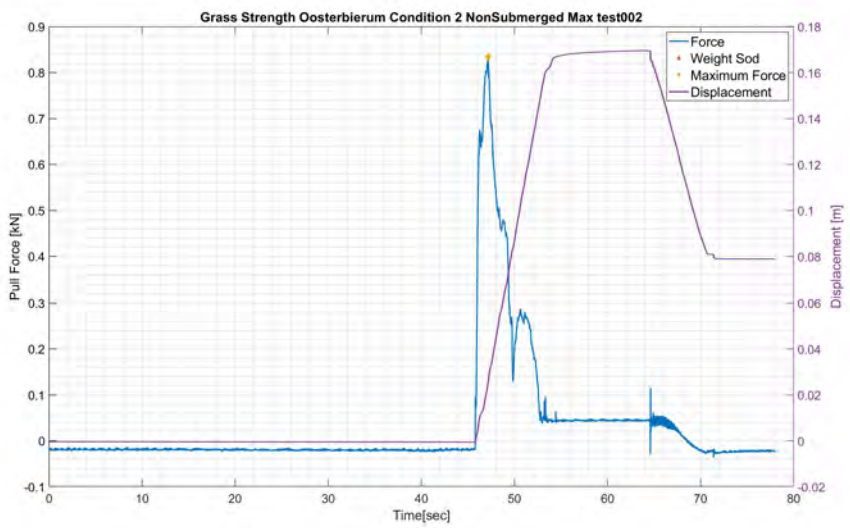
Development of displacement and elasticity are shown as function of number of cycles.

NonSubmerged Condition 2 Max

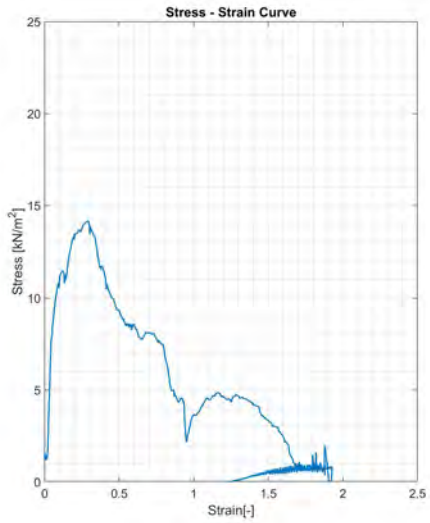
	F max $[N]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test002	827	4.4	28	8.8	1.4
test003	905	5.0	25	10.4	0.8
test004	927	4.4	30	8.8	1.9
test005	715	2.4	28	6.1	3.2
test006	832	3.9	27	6.2	3.8
test007	1056	5.0	NaN	NaN	NaN
test008	1346	3.8	27	12.3	2.1
test009	1060	4.1	24	11.6	2.4
test010	1017	5.5	26	10.1	3.3
test011	848	5.2	28	8.3	3.2
test012	781	4.0	26	8.8	3.3
test013	1284	3.9	34	8.8	3.8
test014	935	NaN	27	7.2	2.9
test015	1376	4.0	32	6.1	3.0
test016	1224	NaN	27	10.0	1.3
Mean	1008	4.3	27.8	8.8	2.6
Median	935	4.1	27	9	3
75th percentile	1183	5.0	28	10	3
25th percentile	836	3.9	28	7	2

test002

		value 1	value 2	value 3	mean
Date		11-3-2019			
Maximum load	$[N]$	827			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	44			
Sod Height	$[cm]$	10	6	0	8.8
Root Length	$[cm]$	2	0	0	1.4
Comments					



Measurement of load and displacement

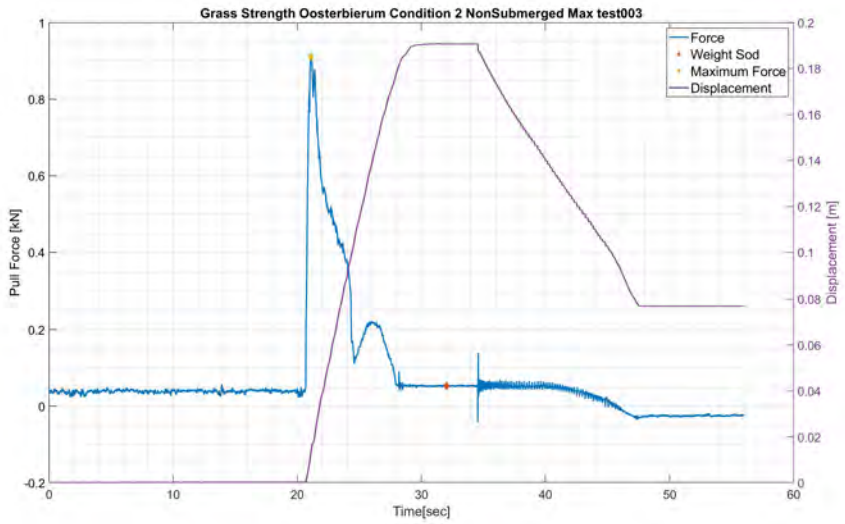


Stress - Strain relation.

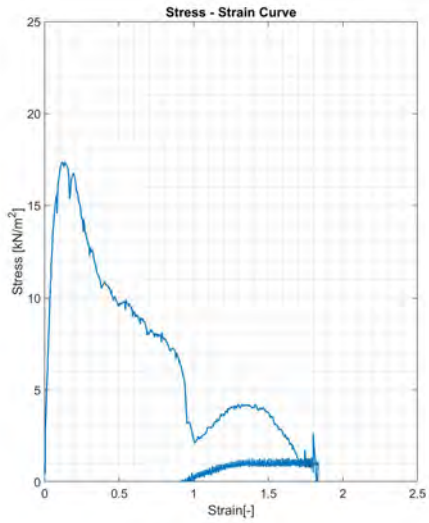
test003

		value 1	value 2	value 3	mean
Date		11-3-2019			
Maximum load	$[N]$	906			
Width Sod	$[cm]$	25			
Weight Sod	$[N]$	50			
Sod Height	$[cm]$	11	8	0	10.4
Root Length	$[cm]$	1	0	0	0.8
Comments					

Figure 10.1: Pictures of tested grass sod.



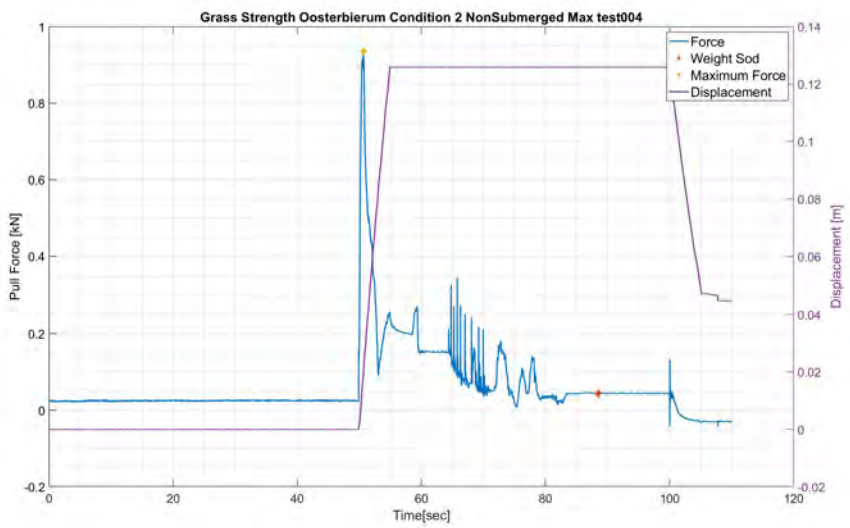
Measurement of load and displacement



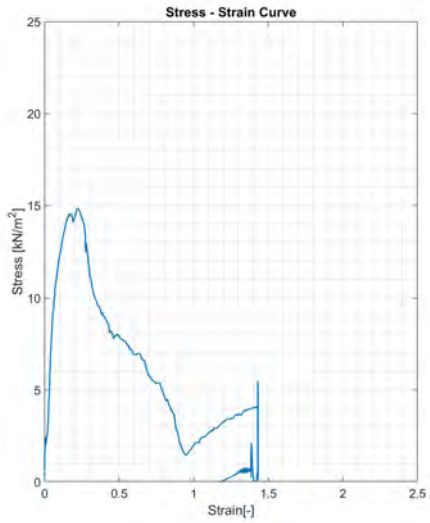
Stress - Strain relation.

test004

		value 1	value 2	value 3	mean
Date		12-3-2019			
Maximum load	$[N]$	927			
Width Sod	$[cm]$	30			
Weight Sod	$[N]$	44			
Sod Height	$[cm]$	12	8	4	8.8
Root Length	$[cm]$	1	2	4	1.9
Comments					



Measurement of load and displacement

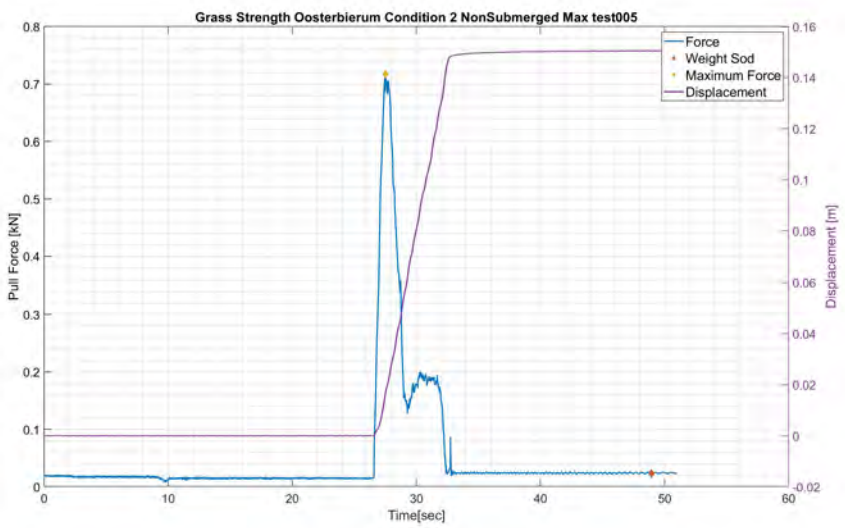


Stress - Strain relation.

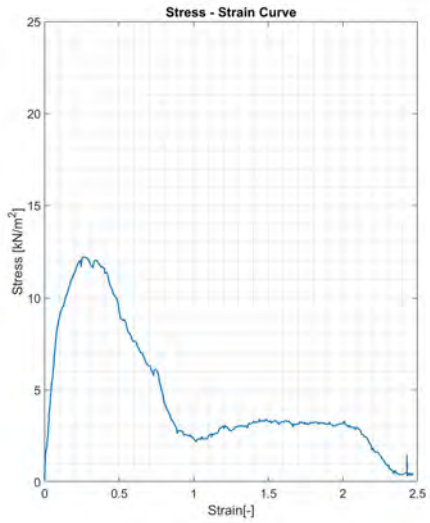
test005

		value 1	value 2	value 3	mean
Date		12-3-2019			
Maximum load	$[N]$	714			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	24			
Sod Height	$[cm]$	9	7	4	6.1
Root Length	$[cm]$	2	4	4	3.2
Comments					

Figure 10.2: Pictures of tested grass sod.



Measurement of load and displacement

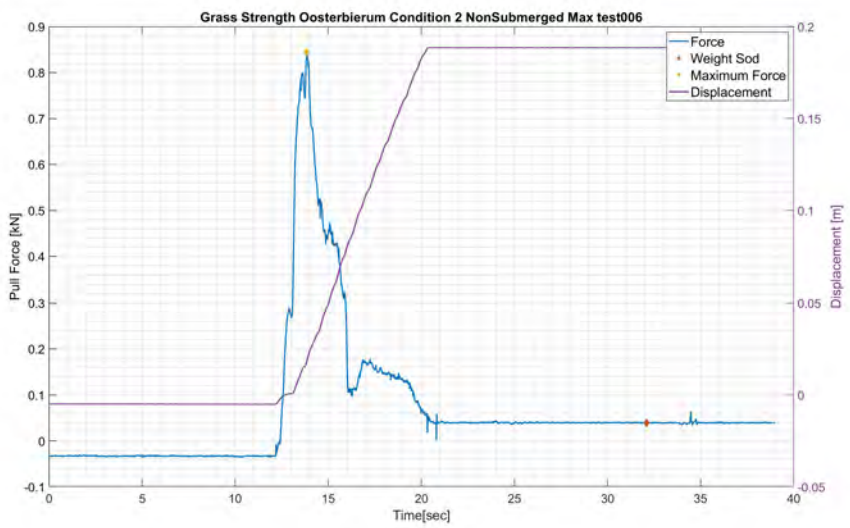


Stress - Strain relation.

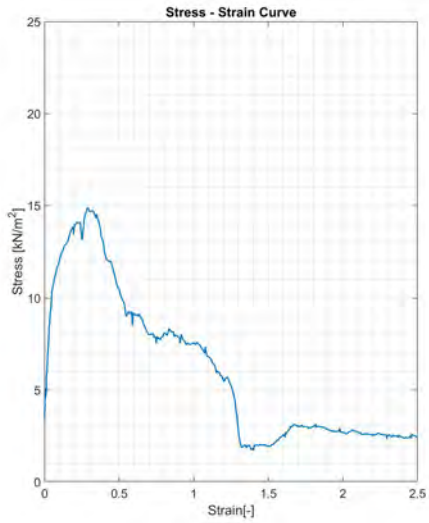
test006

		value 1	value 2	value 3	mean
Date		14-3-2019			
Maximum load	$[N]$	834			
Width Sod	$[cm]$	27			
Weight Sod	$[N]$	39			
Sod Height	$[cm]$	10	8	4	6.2
Root Length	$[cm]$	2	4	4	3.8
Comments					

Figure 10.3: Pictures of tested grass sod.



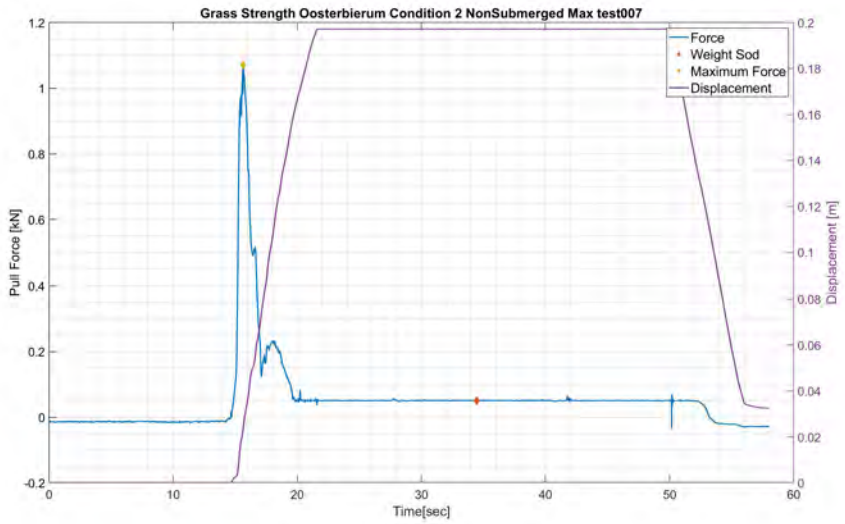
Measurement of load and displacement



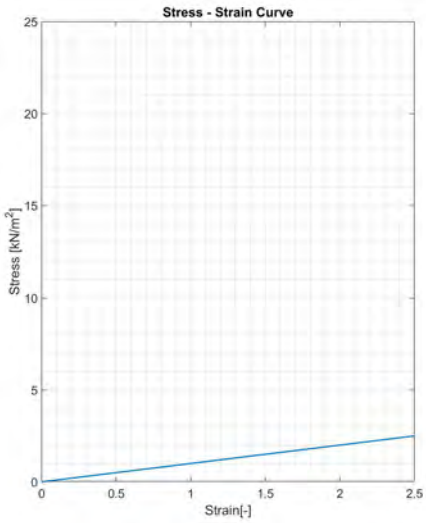
Stress - Strain relation.

test007

	value 1	value 2	value 3	mean
Date				
Maximum load $[N]$	1050			
Width Sod $[cm]$				
Weight Sod $[N]$	50			
Sod Height $[cm]$				
Root Length $[cm]$				
Comments				



Measurement of load and displacement

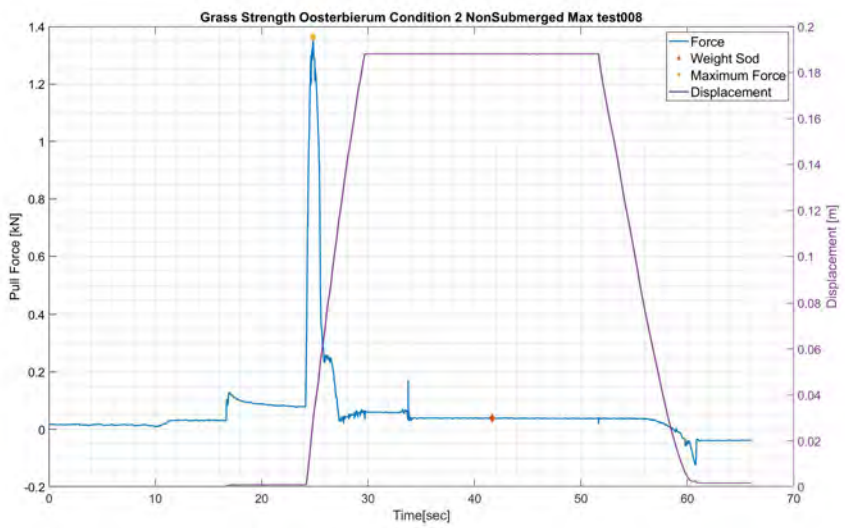


Stress - Strain relation.

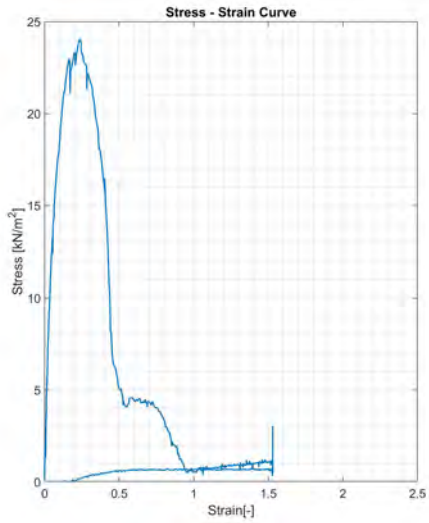
test008

		value 1	value 2	value 3	mean
Date		15-3-2019			
Maximum load	$[N]$	1342			
Width Sod	$[cm]$	27			
Weight Sod	$[N]$	38			
Sod Height	$[cm]$	13	6	0	12.3
Root Length	$[cm]$	2	3	0	2.1
Comments					

Figure 10.4: Pictures of tested grass sod.



Measurement of load and displacement

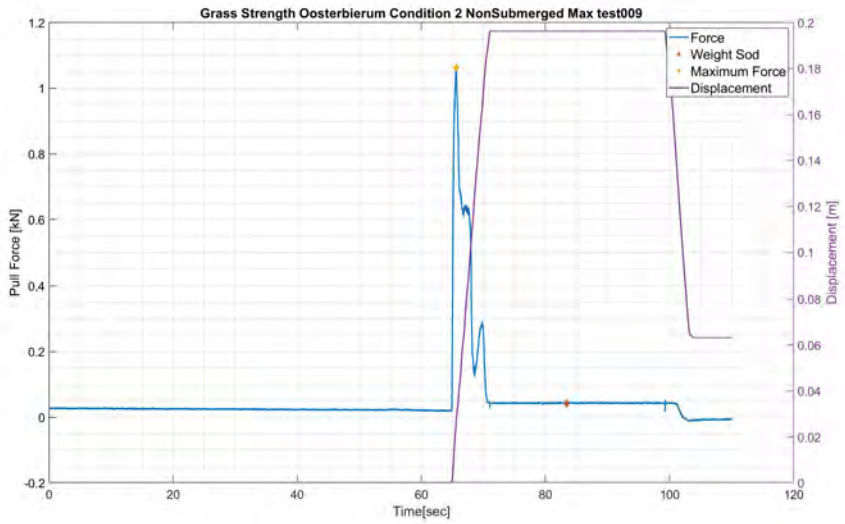


Stress - Strain relation.

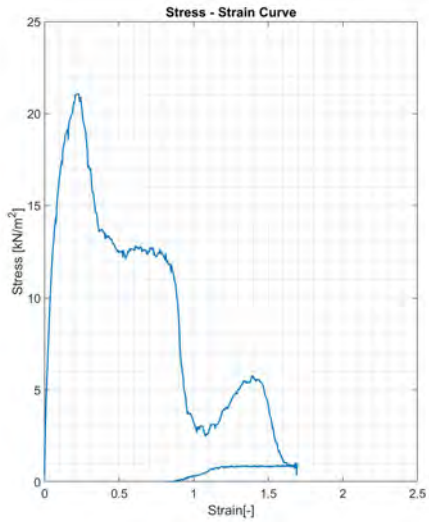
test009

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	1058			
Width Sod	$[cm]$	24			
Weight Sod	$[N]$	41			
Sod Height	$[cm]$	14	12	6	11.6
Root Length	$[cm]$	2	2	6	2.4
Comments					

Figure 10.5: Pictures of tested grass sod.



Measurement of load and displacement

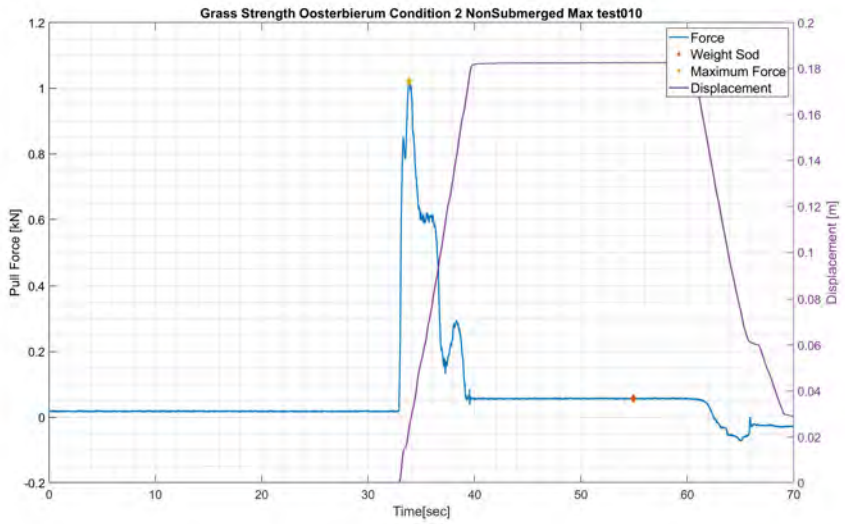


Stress - Strain relation.

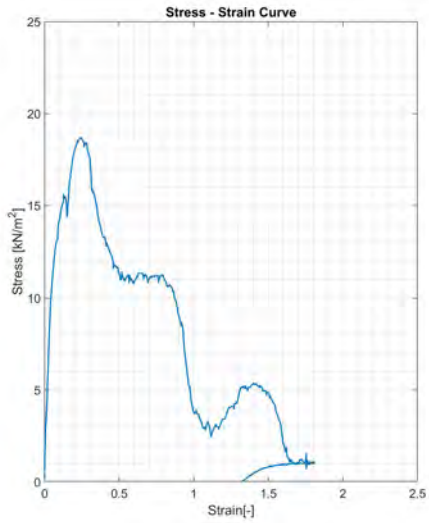
test010

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	1017			
Width Sod	$[cm]$	26			
Weight Sod	$[N]$	55			
Sod Height	$[cm]$	14	11	5	10.1
Root Length	$[cm]$	2	3	5	3.3
Comments					

Figure 10.6: Pictures of tested grass sod.



Measurement of load and displacement

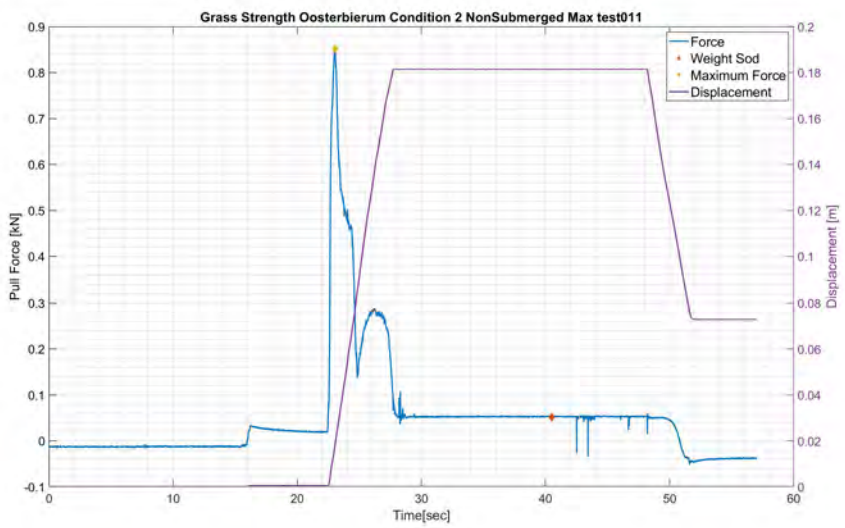


Stress - Strain relation.

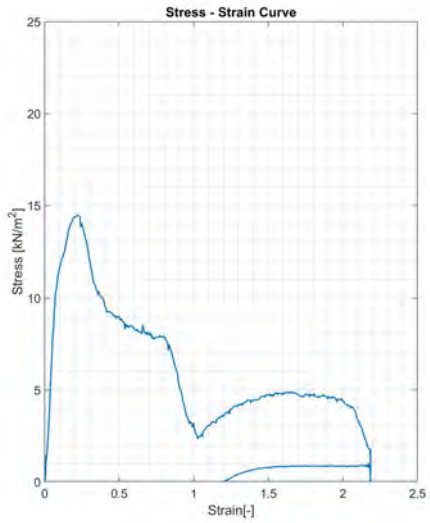
test011

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	847			
Width Sod	$[cm]$	28			
Weight Sod	$[N]$	52			
Sod Height	$[cm]$	11	10	4	8.3
Root Length	$[cm]$	2	3	4	3.2
Comments					

Figure 10.7: Pictures of tested grass sod.



Measurement of load and displacement

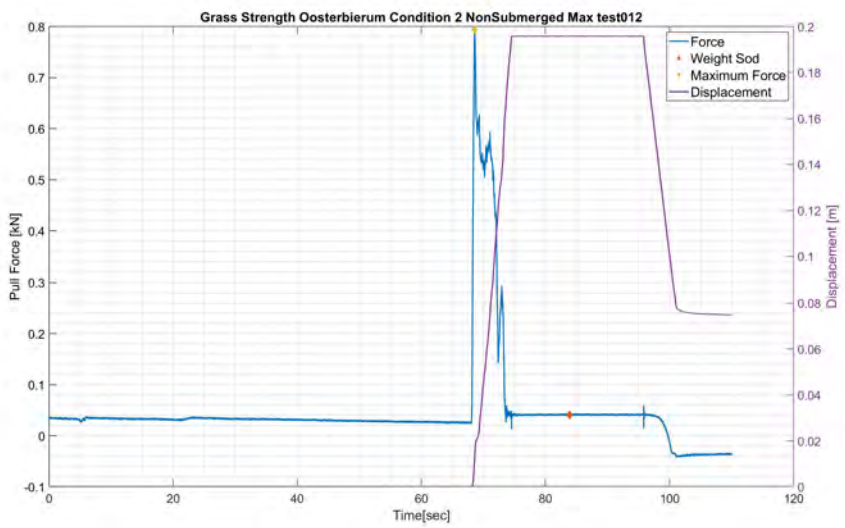


Stress - Strain relation.

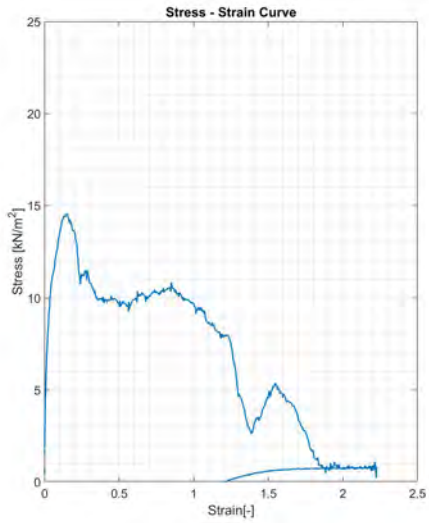
test012

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	782			
Width Sod	$[cm]$	26			
Weight Sod	$[N]$	40			
Sod Height	$[cm]$	11	9	6	8.8
Root Length	$[cm]$	1.5	3	6	3.3
Comments					

Figure 10.8: Pictures of tested grass sod.



Measurement of load and displacement

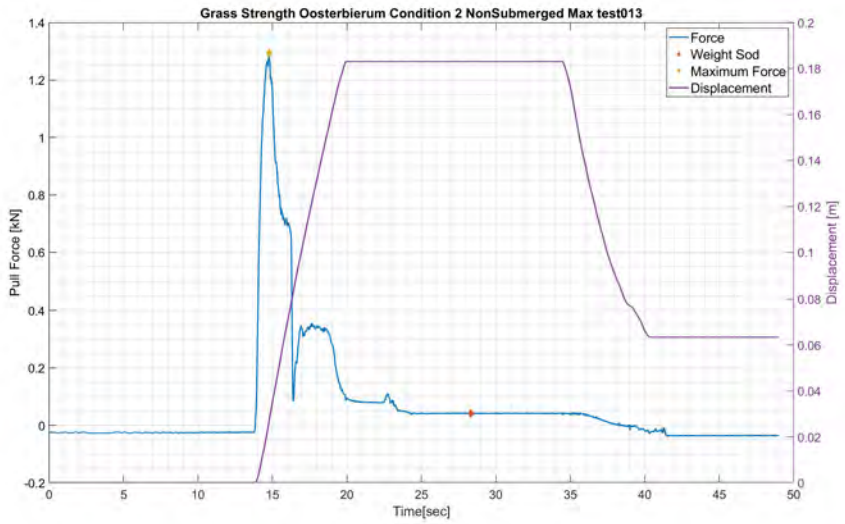


Stress - Strain relation.

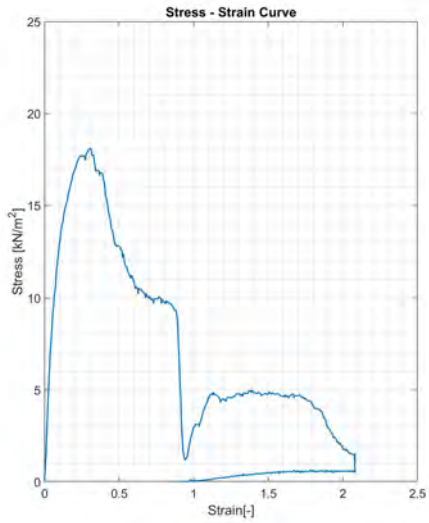
test013

		value 1	value 2	value 3	mean
Date		15-4-2019			
Maximum load	$[N]$	1281			
Width Sod	$[cm]$	34			
Weight Sod	$[N]$	39			
Sod Height	$[cm]$	12	8	6	8.8
Root Length	$[cm]$	2	4	6	3.8
Comments					

Figure 10.9: Pictures of tested grass sod.



Measurement of load and displacement

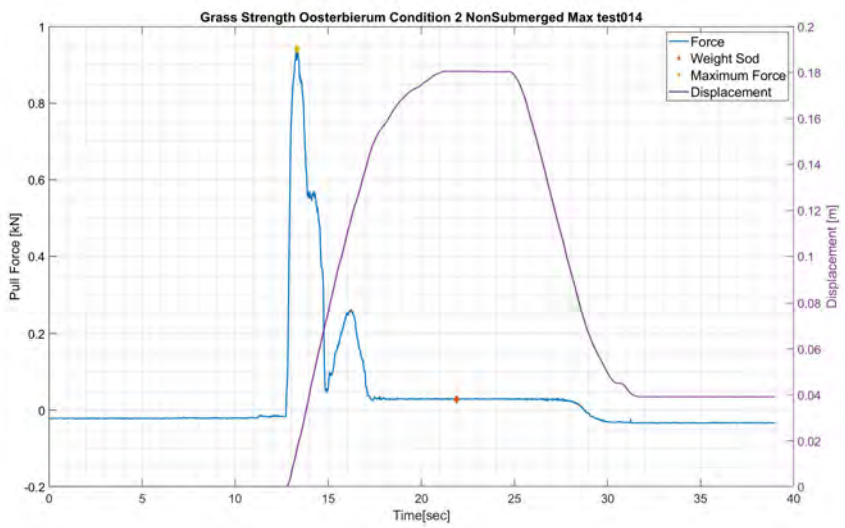


Stress - Strain relation.

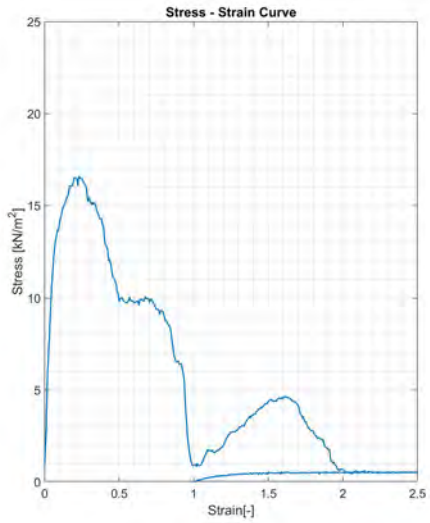
test014

		value 1	value 2	value 3	mean
Date		15-4-2019			
Maximum load	$[N]$	933			
Width Sod	$[cm]$	27			
Weight Sod	$[N]$	NaN			
Sod Height	$[cm]$	10	8	3	7.2
Root Length	$[cm]$	2	3	3	2.9
Comments		Emelten			

Figure 10.10: Pictures of tested grass sod.



Measurement of load and displacement

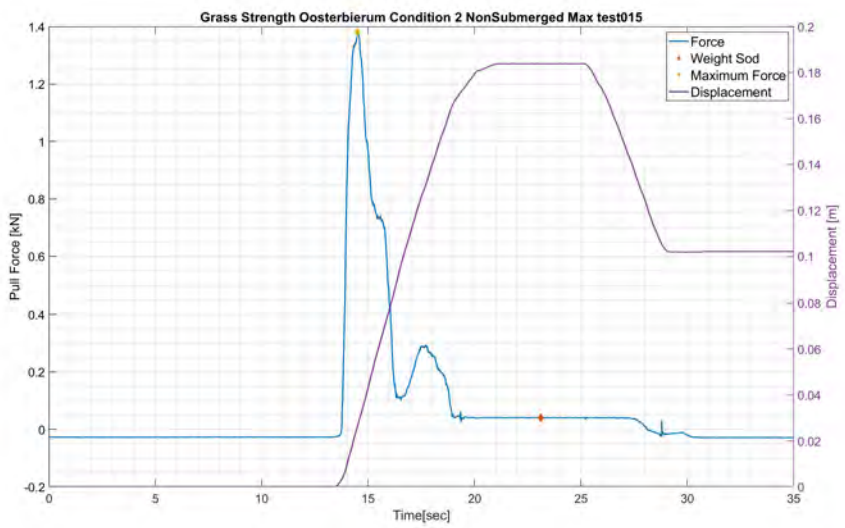


Stress - Strain relation.

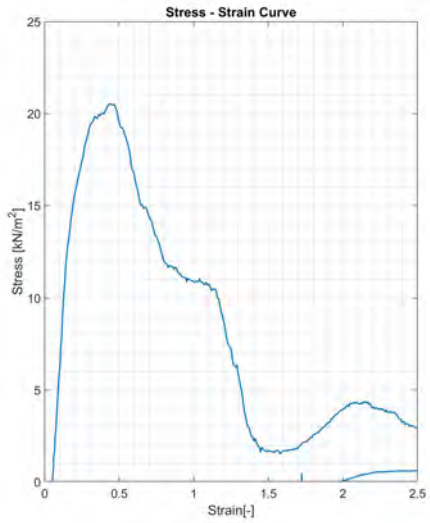
test015

		value 1	value 2	value 3	mean
Date		15-4-2019			
Maximum load	$[N]$	1375			
Width Sod	$[cm]$	32			
Weight Sod	$[N]$	40			
Sod Height	$[cm]$	11	8	3	6.1
Root Length	$[cm]$	3	3	3	3
Comments					

Figure 10.11: Pictures of tested grass sod.



Measurement of load and displacement

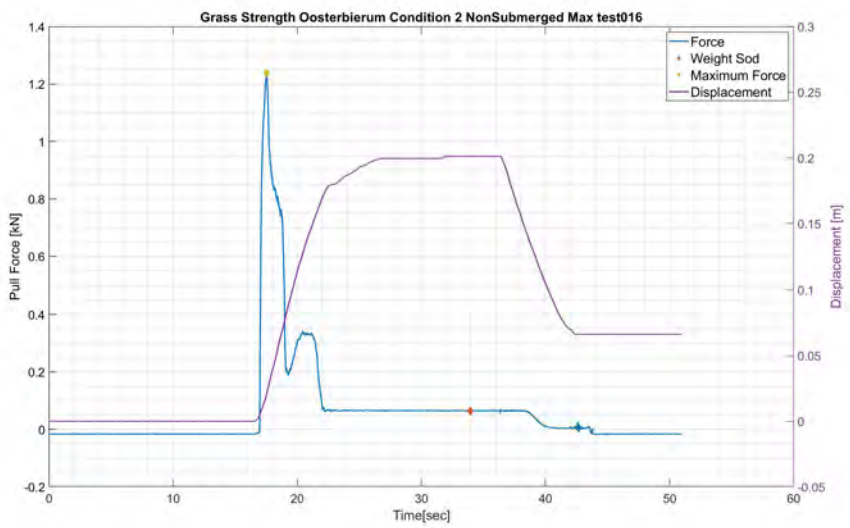


Stress - Strain relation.

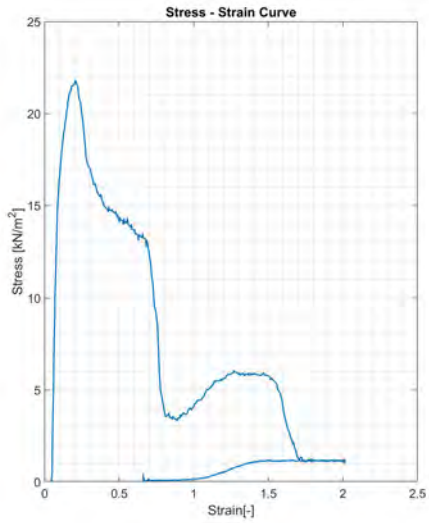
test016

		value 1	value 2	value 3	mean
Date		18-4-2019			
Maximum load	$[N]$	1225			
Width Sod	$[cm]$	27			
Weight Sod	$[N]$	NaN			
Sod Height	$[cm]$	11	8	4	10
Root Length	$[cm]$	1	1	4	1.3
Comments					

Figure 10.12: Pictures of tested grass sod.



Measurement of load and displacement



Stress - Strain relation.

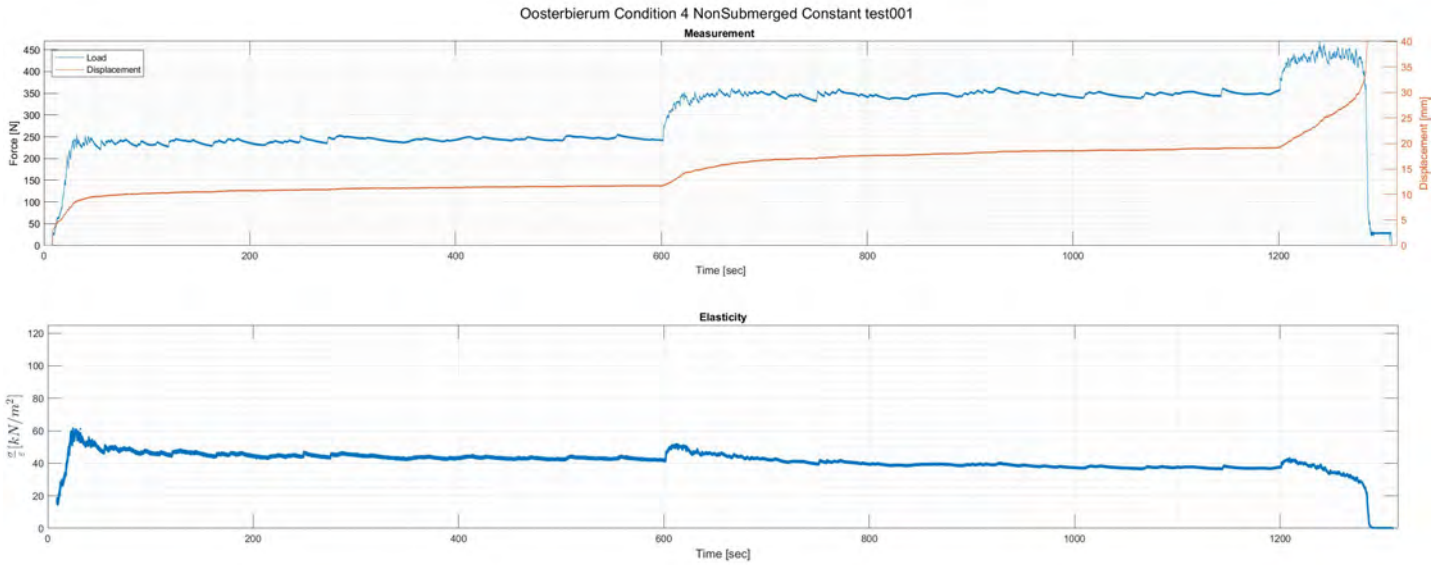
Submerged Condition 2 Constant

	Time to reach 80% of displacement $[sec]$	$E\,[kN/m^2]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test005	26	56.78	2.6	21.0	8.5	2.7
test004	59	25.95	2.5	21.0	9.4	2.7
test003	38	98.09	4.6	21.0	9.0	2.6
test002	36	57.57	1.6	21.0	6.6	3.6
test001	16	42.22	2.2	21.0	7.1	4.1
mean	35	56.12	2.7	21.0	8.1	3.1
median	36	56.78	2.5	21.0	8.5	2.7
75th percentile	43	67.70	3.1	21.0	9.1	3.7
25th percentile	24	38.15	2.0	21.0	7.0	2.7

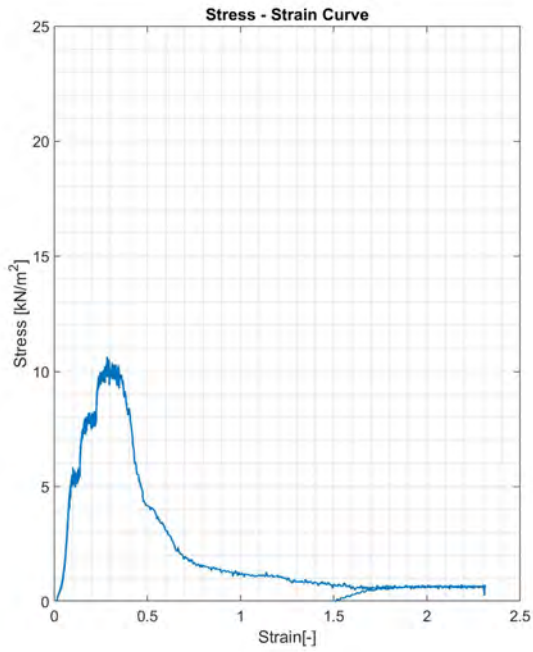
test001

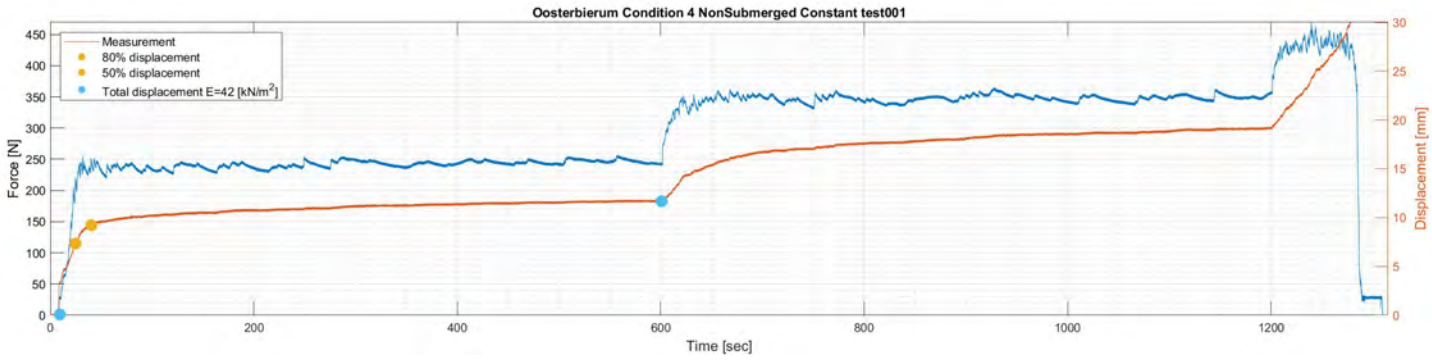
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	42.22			
Time to reach 80% of displacement	$[sec]$	16			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	26			
Sod Height	$[cm]$	12	10	3	8.5
Root Length	$[cm]$	2	3	3	2.7
Comments					

Figure 11.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



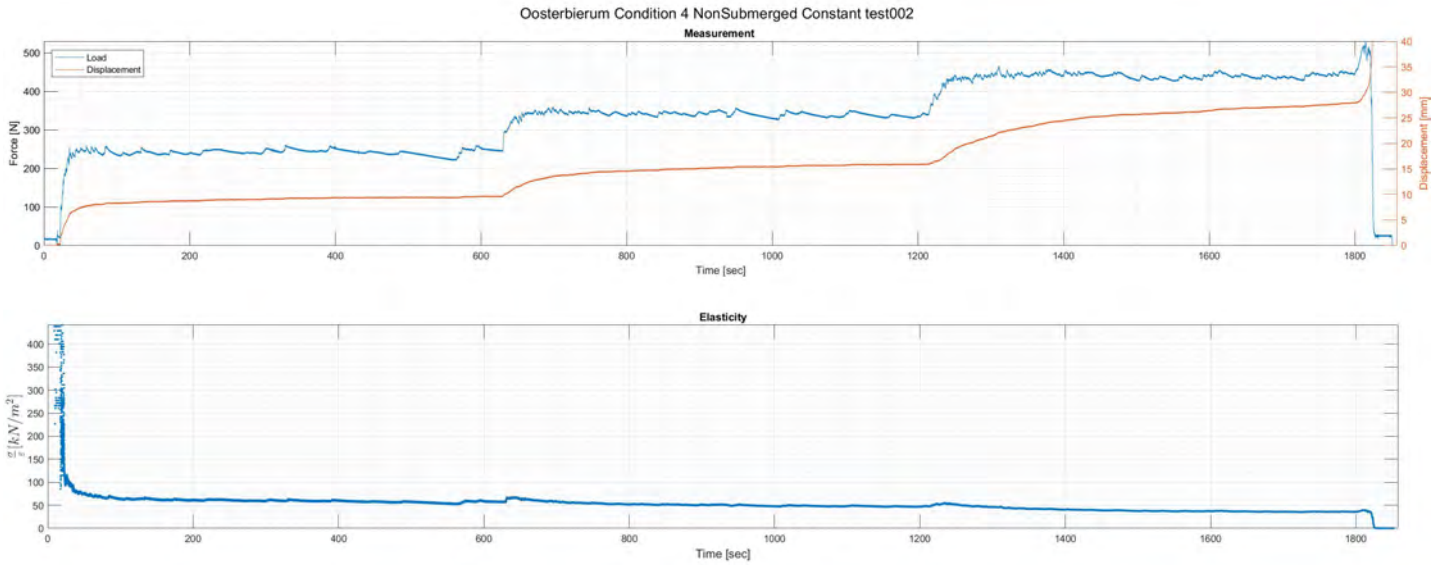


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

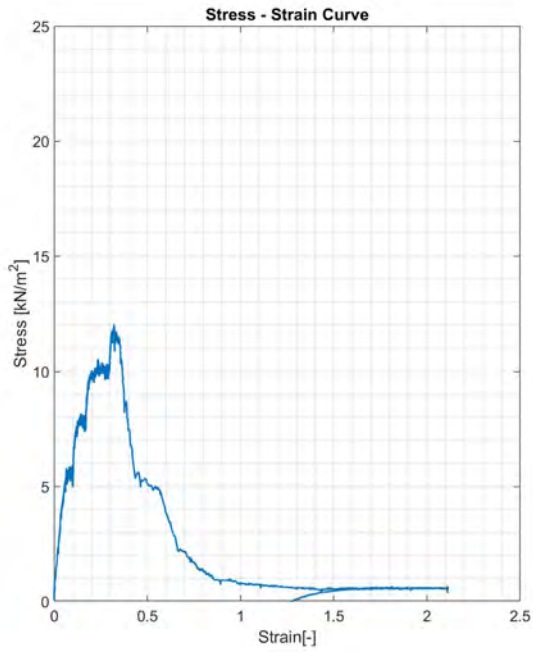
test002

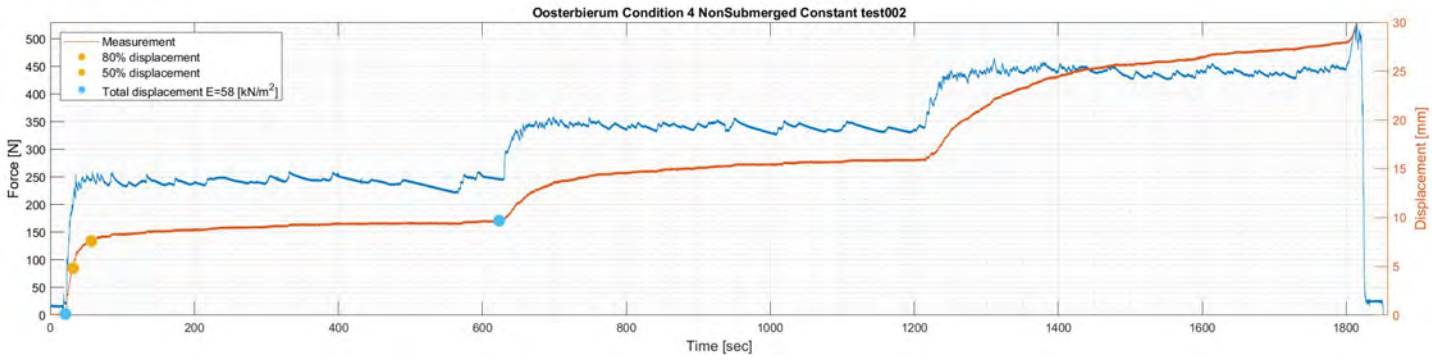
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	57.57			
Time to reach 80% of displacement	$[sec]$	36			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	25			
Sod Height	$[cm]$	10	8	0	9.4
Root Length	$[cm]$	3	2	0	2.7
Comments					

Figure 11.2: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



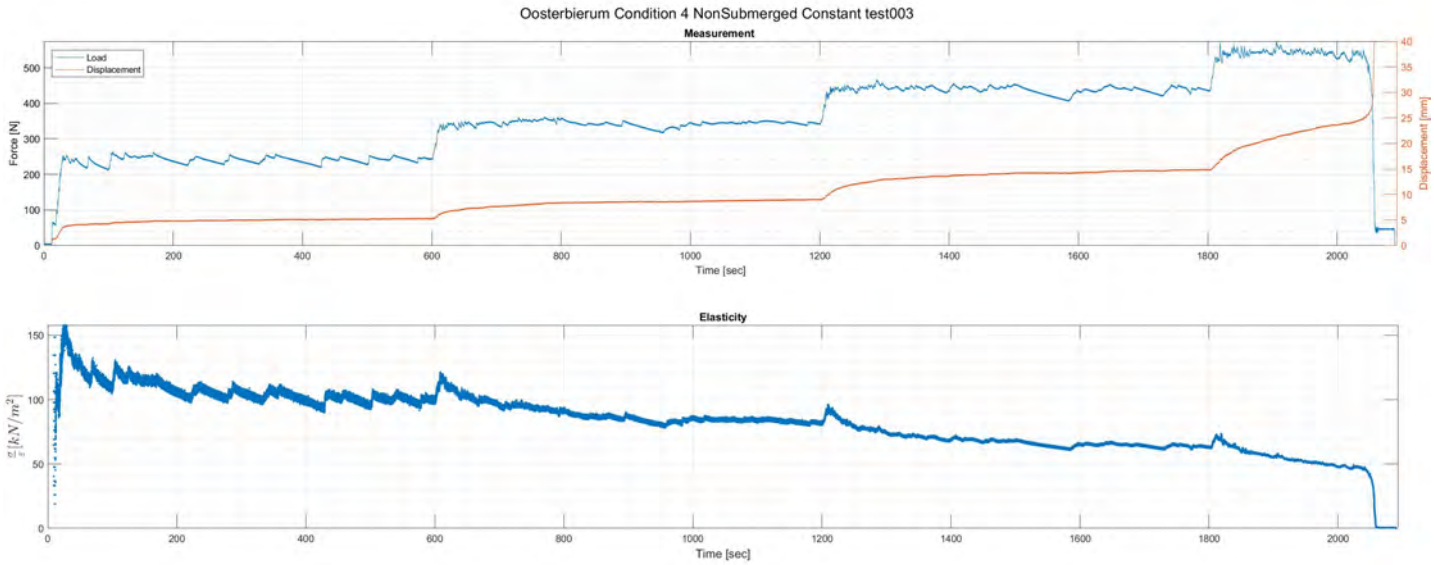


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

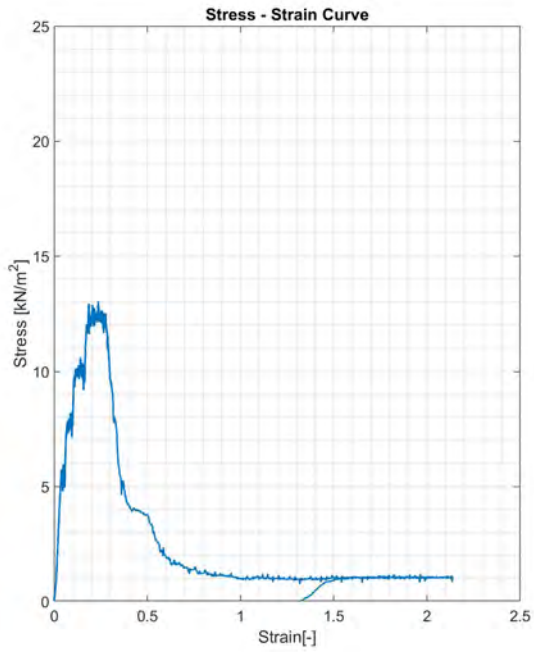
test003

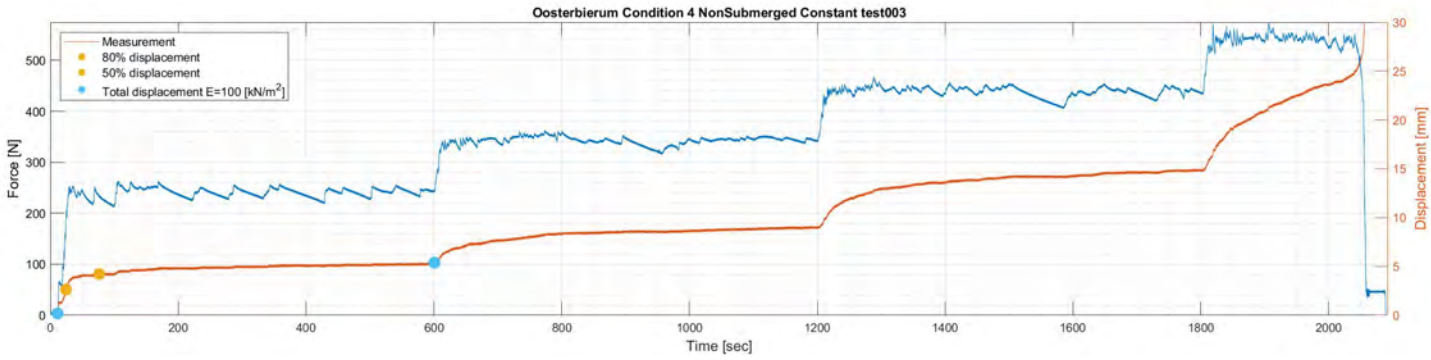
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	98.09			
Time to reach 80% of displacement	$[sec]$	38			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	46			
Sod Height	$[cm]$	11	8	4	9
Root Length	$[cm]$	2	3	4	2.6
Comments					

Figure 11.3: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



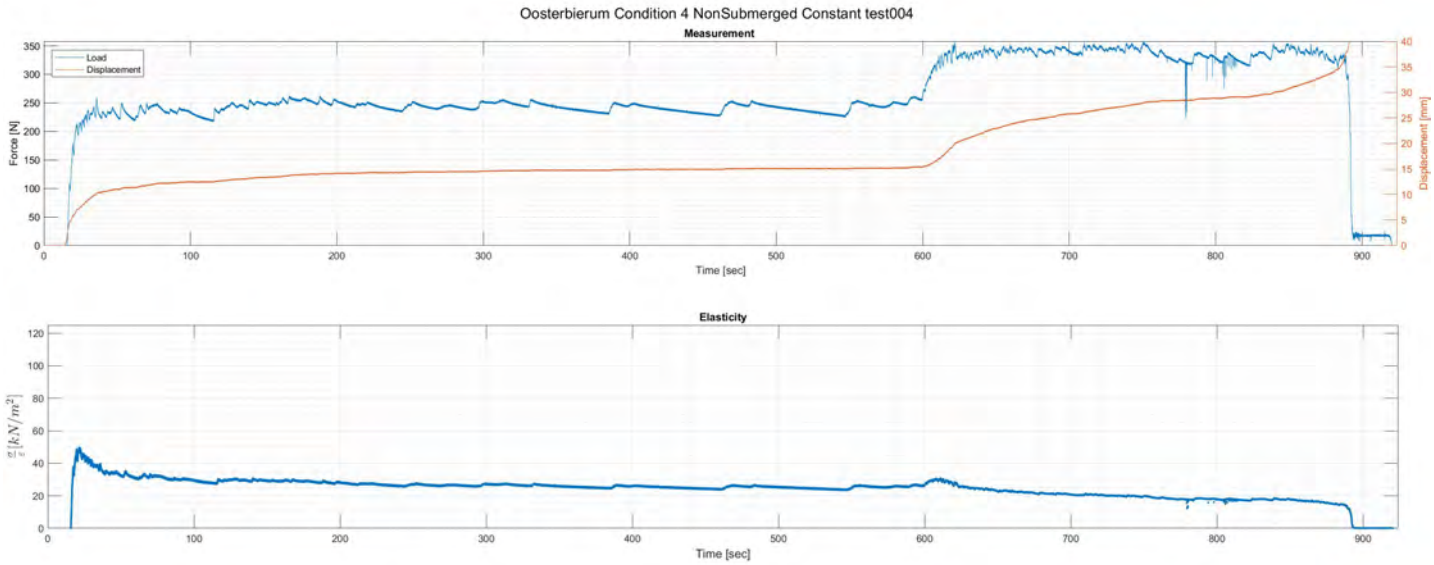


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

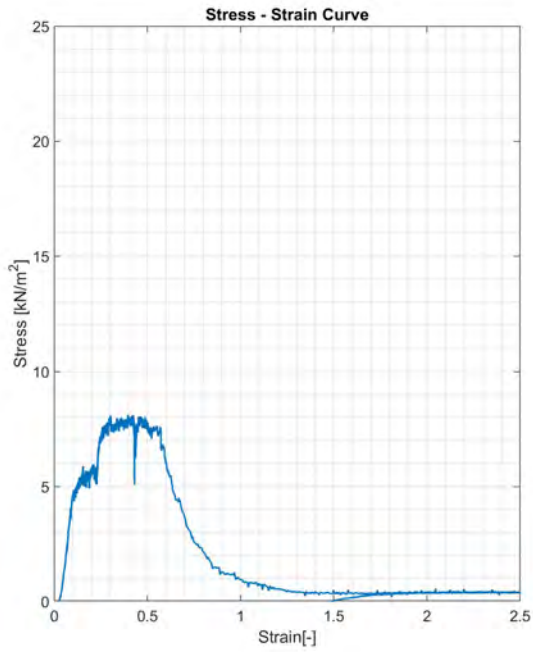
test004

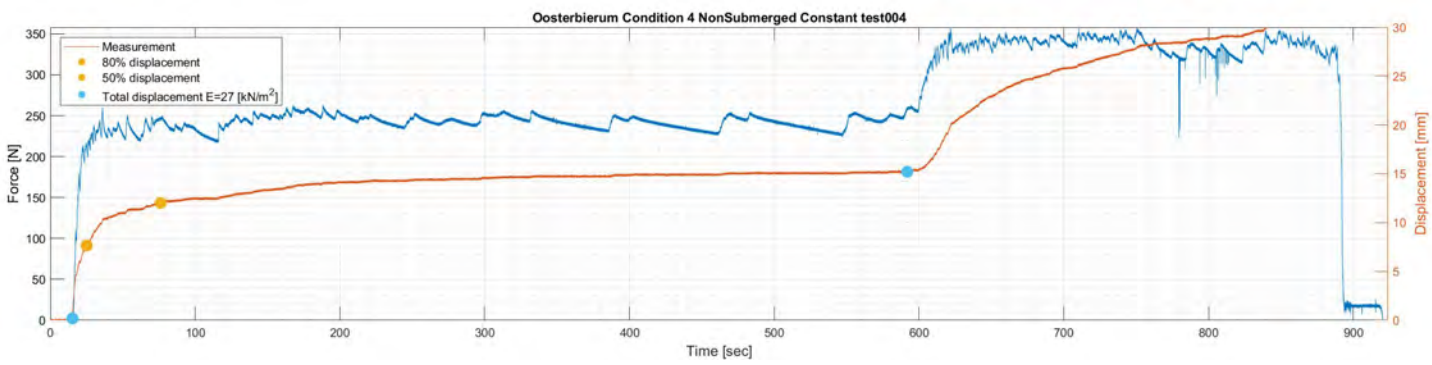
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	25.95			
Time to reach 80% of displacement	$[sec]$	59			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	16			
Sod Height	$[cm]$	11	7	4	6.6
Root Length	$[cm]$	2	4	4	3.6
Comments					

Figure 11.4: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



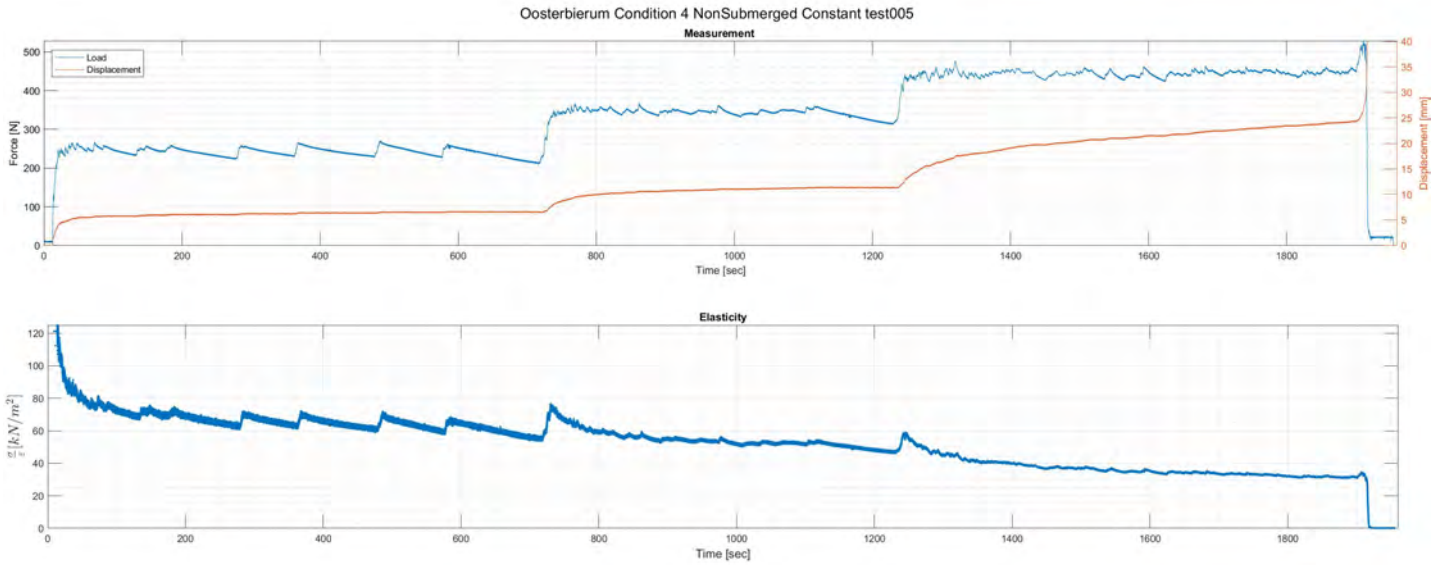


Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

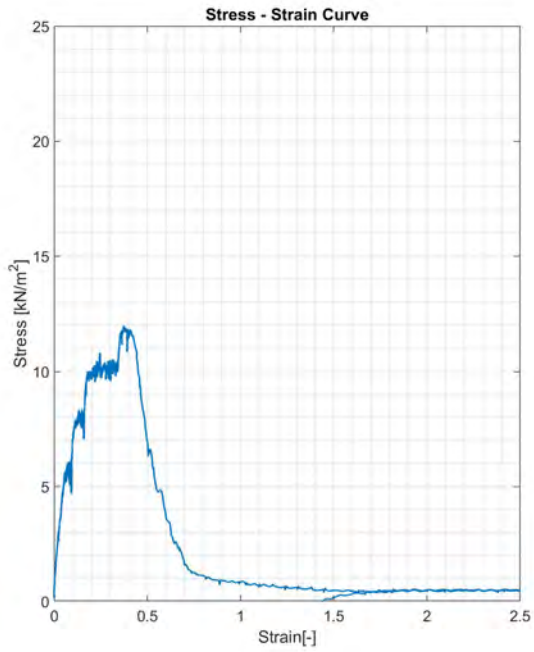
test005

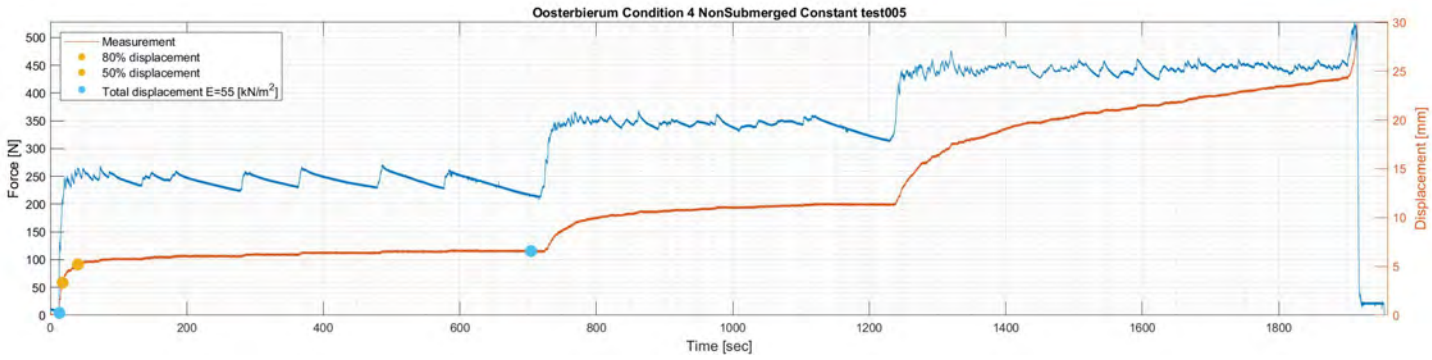
		value 1	value 2	value 3	mean
Date		20-3-2019			
E	$[kN/m^2]$	56.78			
Time to reach 80% of displacement	$[sec]$	26			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	22			
Sod Height	$[cm]$	10	8	5	7.1
Root Length	$[cm]$	2	5	5	4.1
Comments					

Figure 11.5: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.





Displacement rate under step increased constant loading. The blue dots indicate the total or final displacement as result of the induced load during the first 600 seconds of loading. The yellow dot indicates 80% of the final displacement

NonSubmerged Condition 4 Cyclic

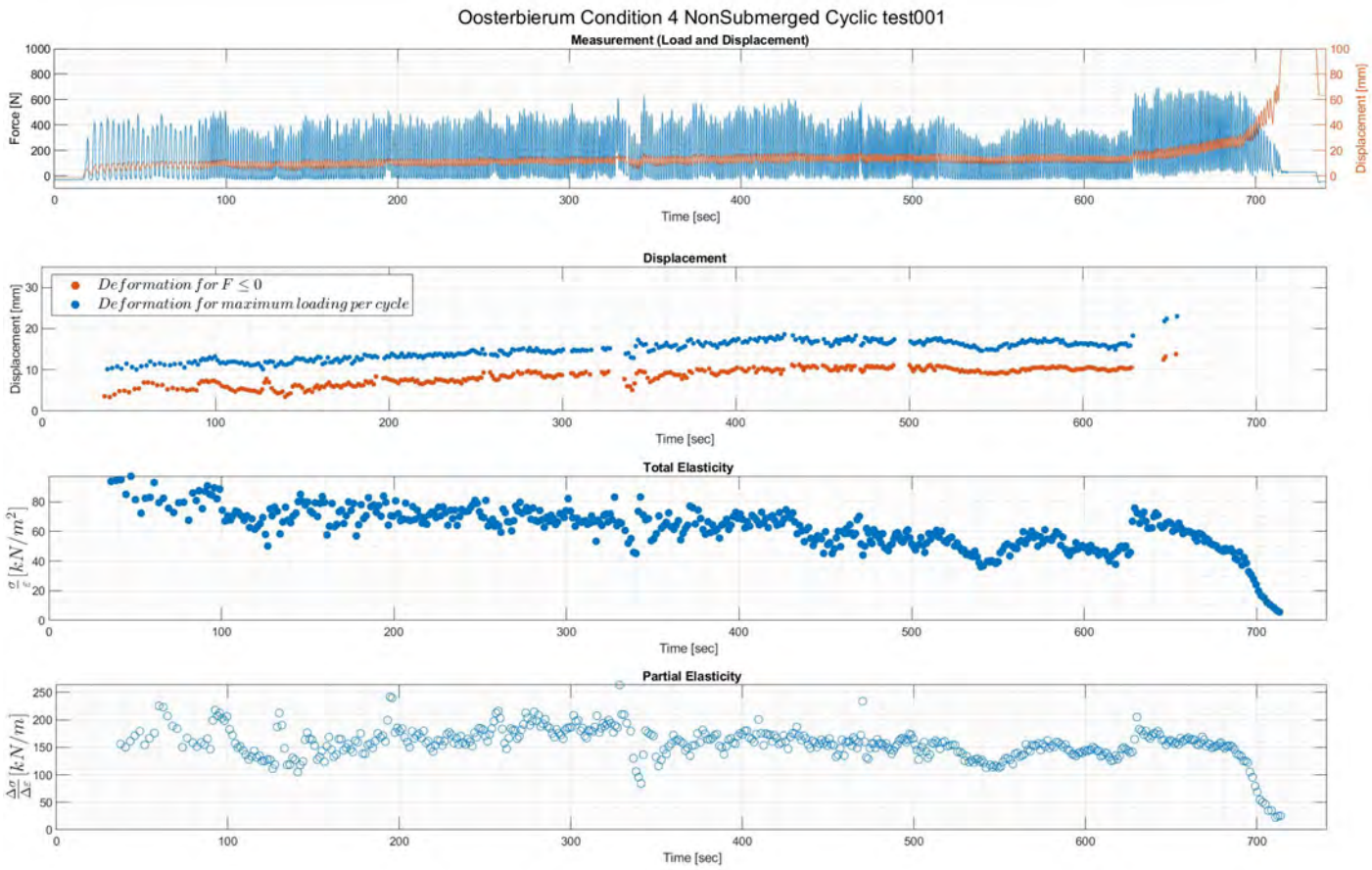
	Growth rate $\frac{\Delta U}{n}$ $[mm]$						Load					
	Plastic deformation			Maximum deformation			Mean			Mean maximum		
Load block	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800	0-600	600-1200	1200-1800
test001	1.30e-02	4.45e-01	NaN	1.38e-02	4.50e-01	NaN	1.96e+02	3.06e+02	NaN	4.12e+02	5.83e+02	NaN
test002	2.24e-01	NaN	NaN	6.42e-01	NaN	NaN	3.50e+02	NaN	NaN	7.76e+02	NaN	NaN
test003	7.72e-04	1.28e-02	NaN	1.14e-03	2.89e-02	NaN	8.18e+01	2.05e+02	NaN	1.71e+02	4.08e+02	NaN
test004	1.31e-03	2.06e-02	NaN	1.62e-03	3.81e-02	NaN	1.54e+02	2.93e+02	NaN	2.91e+02	5.68e+02	NaN
test005	3.43e-04	3.61e-03	NaN	5.99e-04	6.53e-03	NaN	1.05e+02	2.23e+02	NaN	2.11e+02	4.43e+02	NaN
mean	4.79e-02	1.20e-01	NaN	1.32e-01	1.31e-01	NaN	1.77e+02	2.57e+02	NaN	3.72e+02	5.01e+02	NaN
median	1.31e-03	1.67e-02	NaN	1.62e-03	3.35e-02	NaN	1.54e+02	2.58e+02	NaN	2.91e+02	5.06e+02	NaN
75th percentile	6.58e-02	2.33e-01	NaN	1.71e-01	2.44e-01	NaN	2.35e+02	2.99e+02	NaN	5.03e+02	5.76e+02	NaN
25th percentile	6.65e-04	8.19e-03	NaN	1.00e-03	1.77e-02	NaN	9.89e+01	2.14e+02	NaN	2.01e+02	4.25e+02	NaN

	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test001	3.0	21.0	10.1	7.2
test002	NaN	21.0	8.2	3.0
test003	5.5	21.0	9.9	2.0
test004	5.3	21.0	10.0	2.8
test005	5.6	21.0	10.0	2.5
Mean	4.8	21	9.6	3.5
Median	5.4	21	10	2.8
75th percentile	5.5	21	10	4.1
25th percentile	4.1	21	9.5	2.4

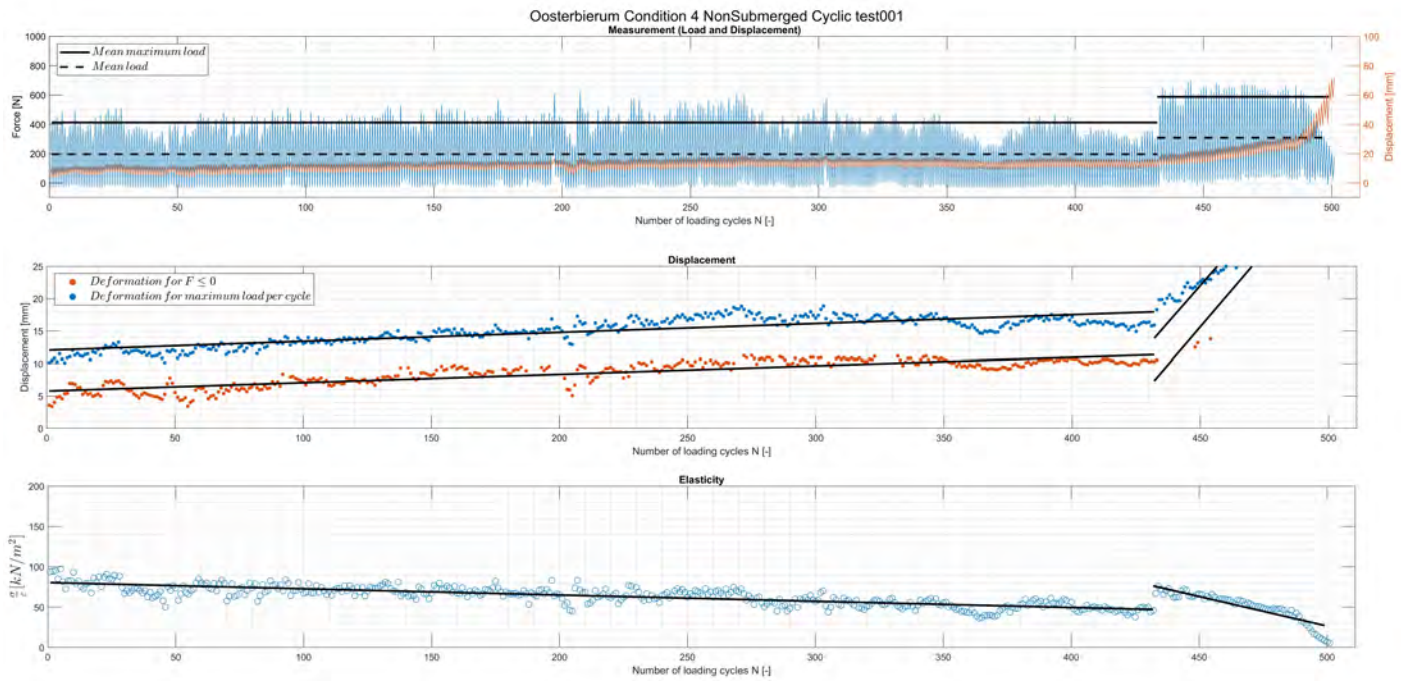
test001

		value 1	value 2	value 3	mean
Date		21-3-2019			
Mean load	$[N]$	1.96e+02	3.06e+02		2.51e+02
Mean maximum load	$[N]$	4.12e+02	5.83e+02		4.98e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	1.30e-02	4.45e-01		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.38e-02	4.50e-01		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	30			
Sod Height	$[cm]$	10	8	7	10.1
Root Length	$[cm]$	3	7	7	7.2
Comments					

Figure 12.1: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

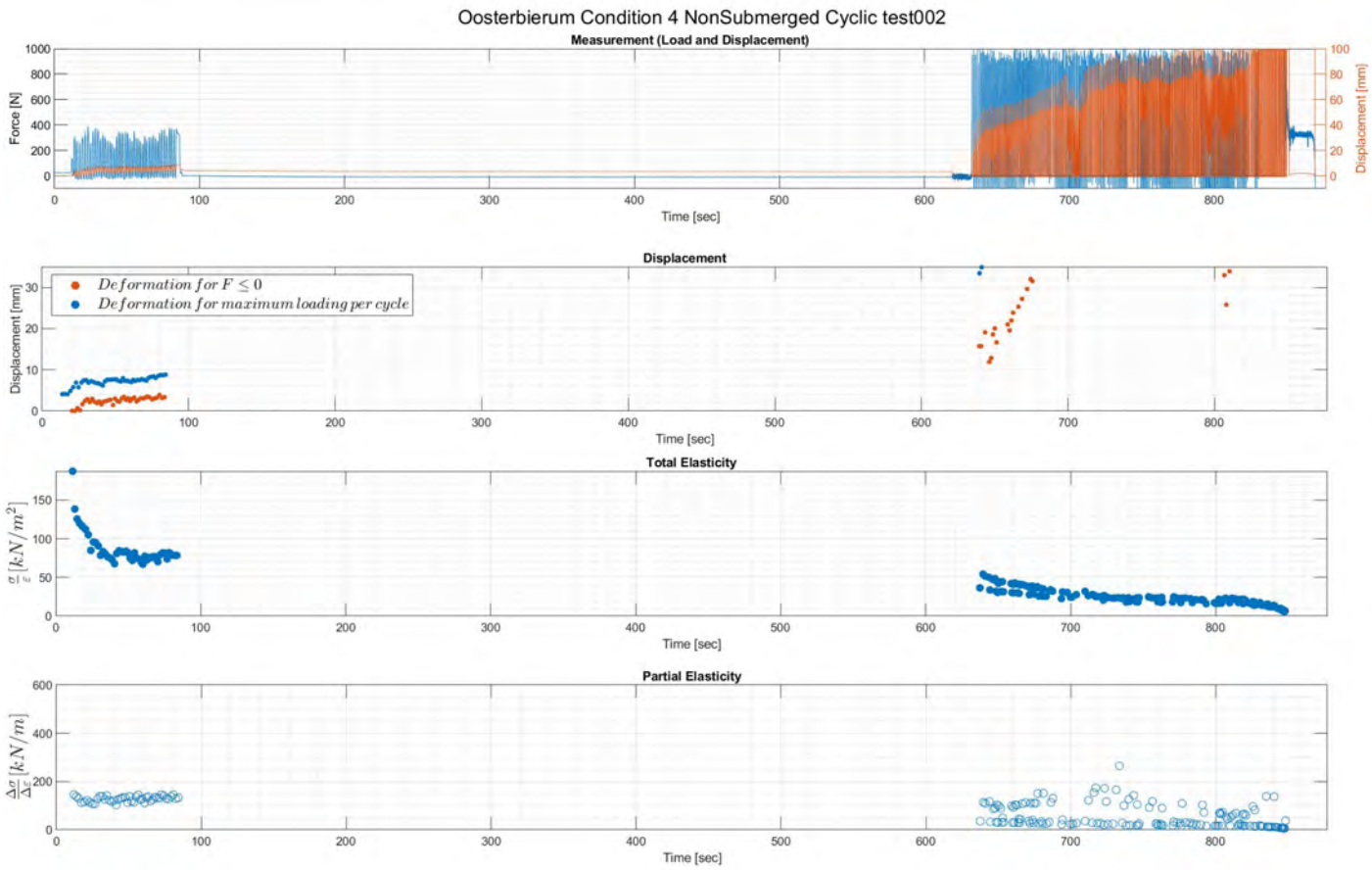


Development of displacement and elasticity are shown as function of number of cycles.

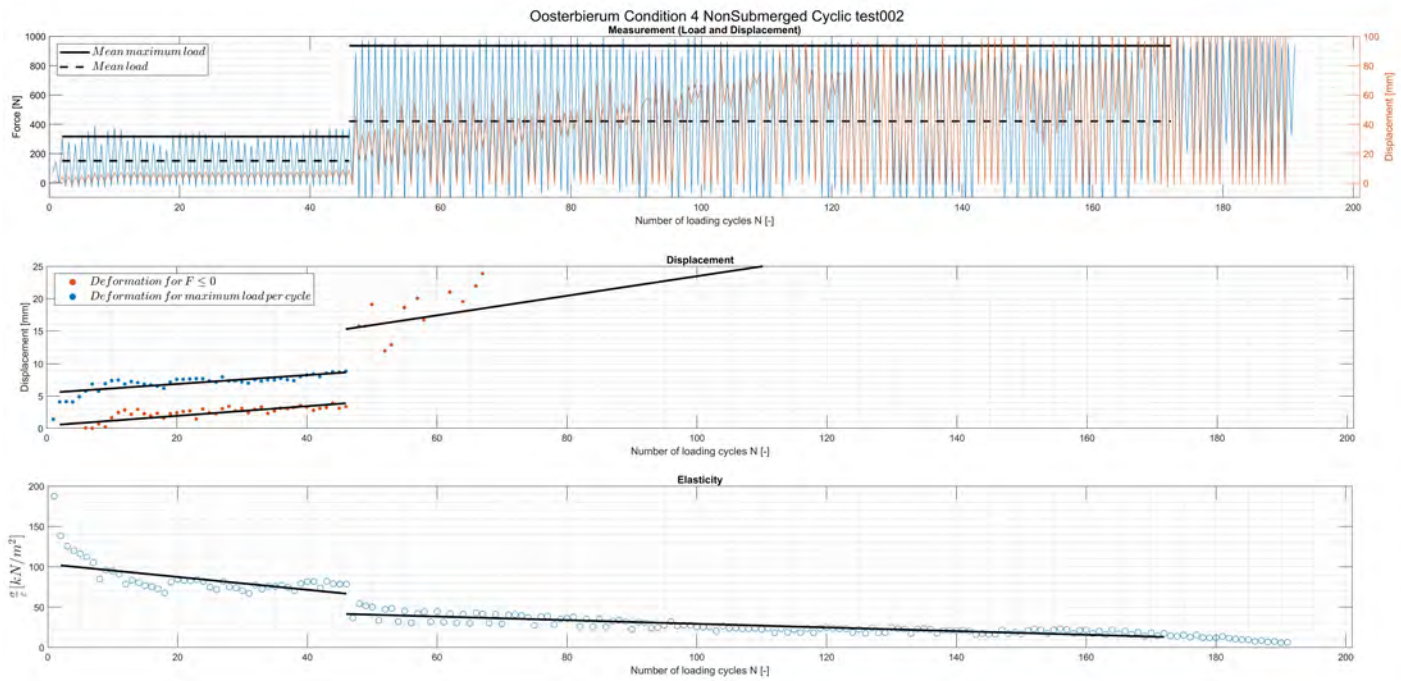
test002

		value 1	value 2	value 3	mean
Date		21-3-2019			
Mean load	$[N]$	3.50e+02			3.50e+02
Mean maximum load	$[N]$	7.76e+02			7.76e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	2.24e-01			
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	6.42e-01			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	NaN			
Sod Height	$[cm]$	11	9	3	8.2
Root Length	$[cm]$	3	3	3	3
Comments					

Figure 12.2: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

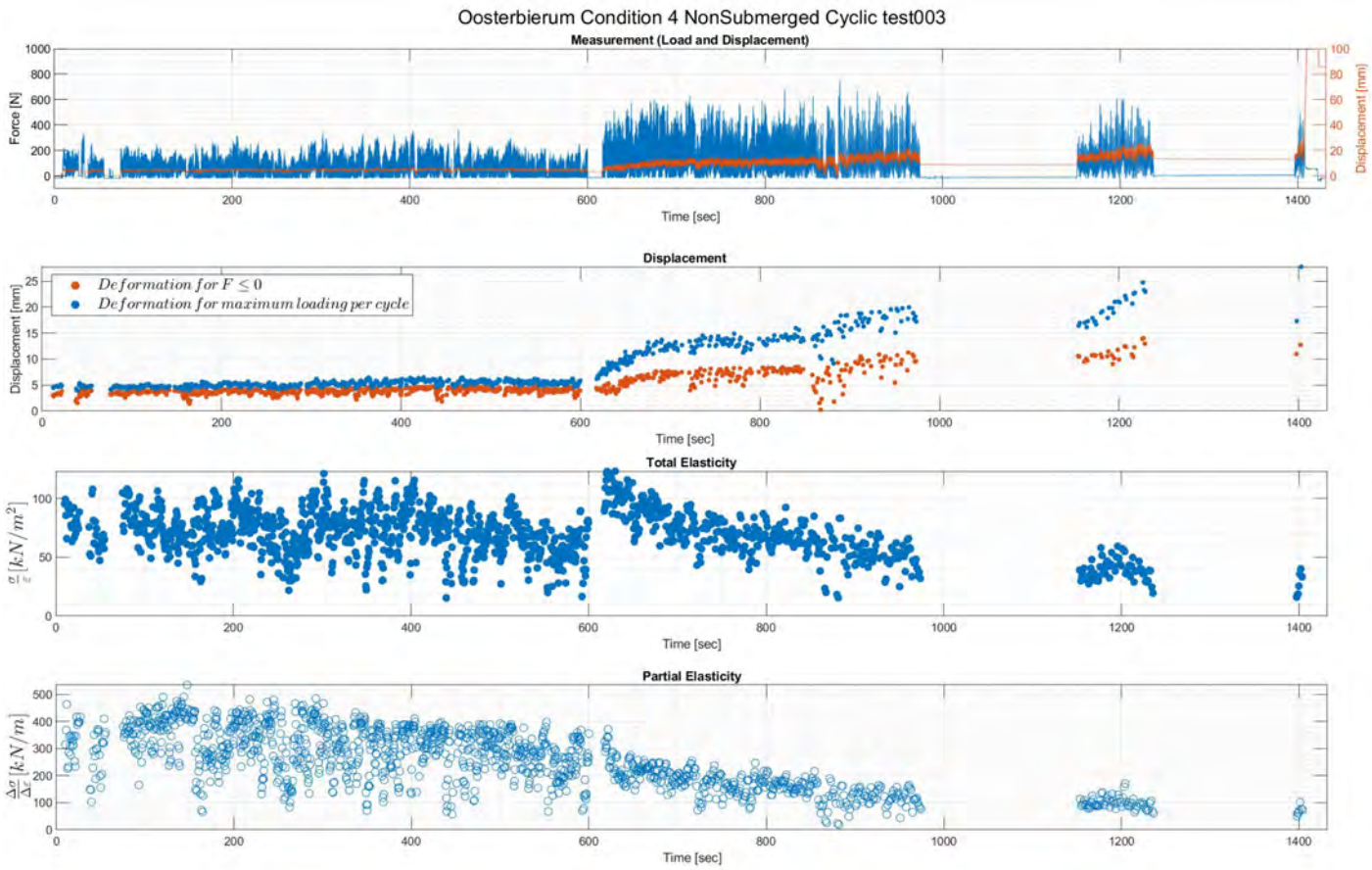


Development of displacement and elasticity are shown as function of number of cycles.

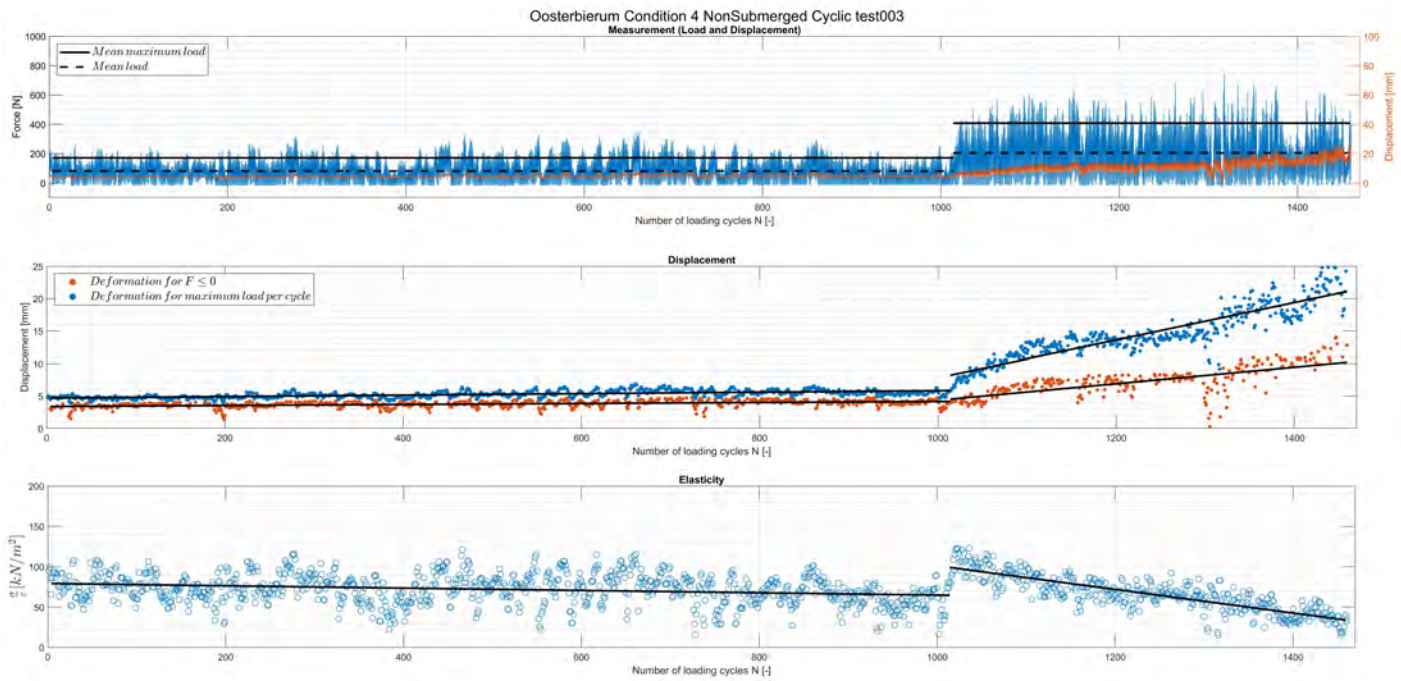
test003

		value 1	value 2	value 3	mean
Date		18-4-2019			
Mean load	$[N]$	8.18e+01	2.05e+02		1.43e+02
Mean maximum load	$[N]$	1.71e+02	4.08e+02		2.90e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	7.72e-04	1.28e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.14e-03	2.89e-02		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	54			
Sod Height	$[cm]$	12	9	3	9.9
Root Length	$[cm]$	1	3	3	2
Comments					

Figure 12.3: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

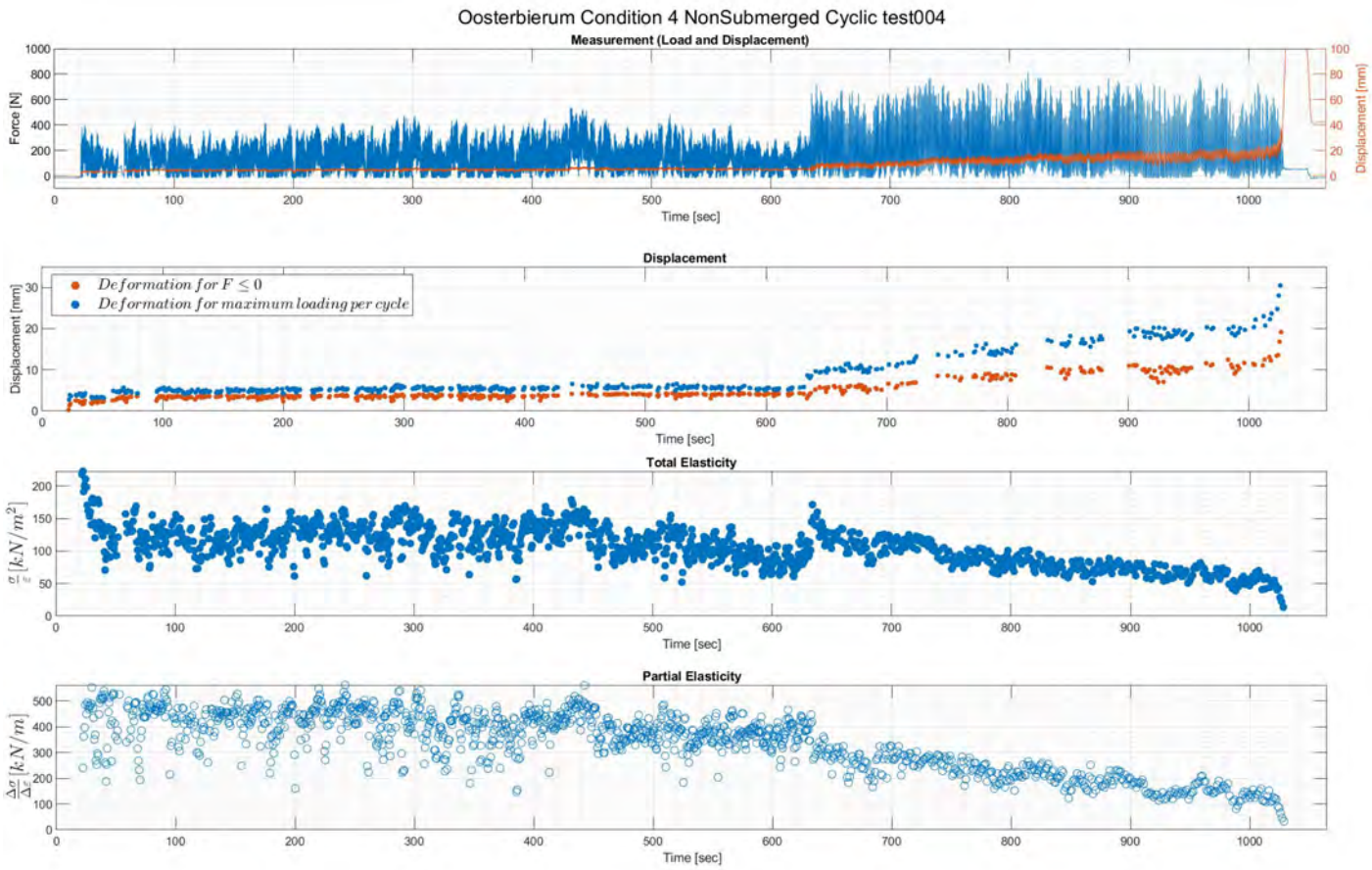


Development of displacement and elasticity are shown as function of number of cycles.

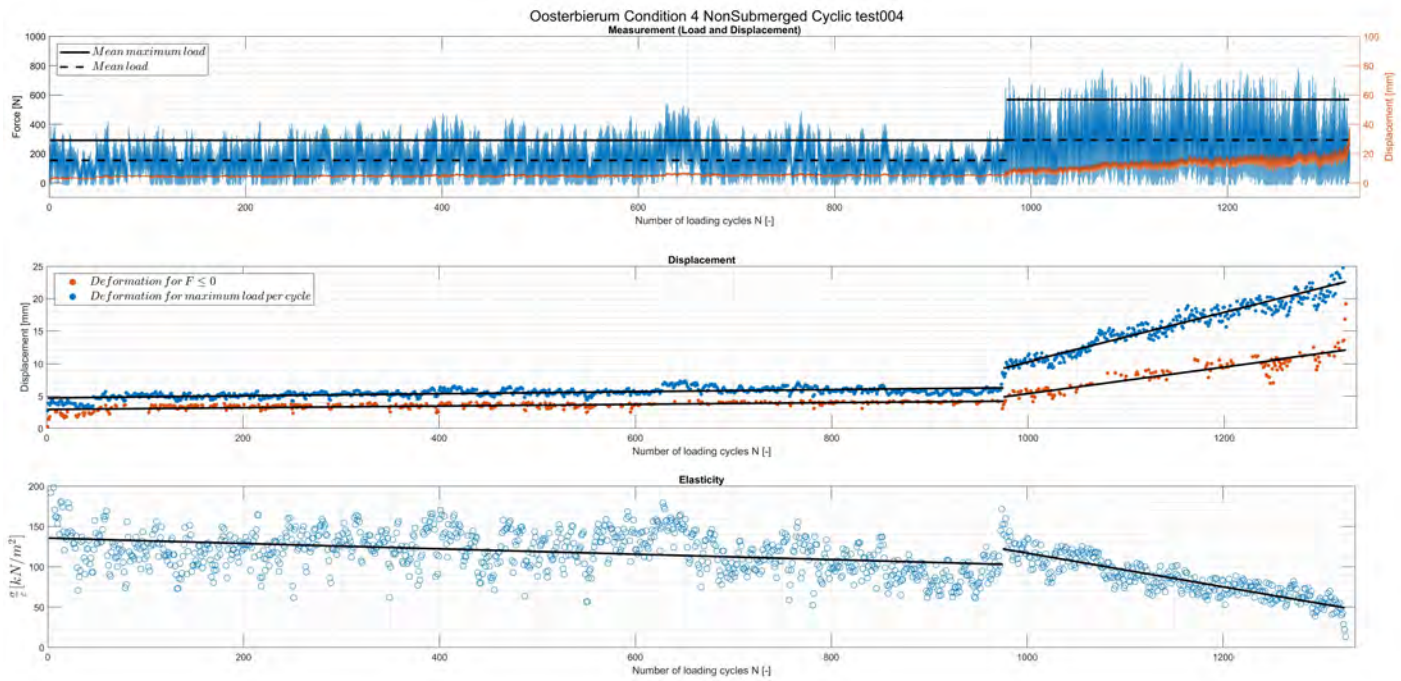
test004

		value 1	value 2	value 3	mean
Date		18-4-2019			
Mean load	$[N]$	1.54e+02	2.93e+02		2.24e+02
Mean maximum load	$[N]$	2.91e+02	5.68e+02		4.30e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	1.31e-03	2.06e-02		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	1.62e-03	3.81e-02		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	53			
Sod Height	$[cm]$	12	7	0	10
Root Length	$[cm]$	2	4	0	2.8
Comments		Opvallende verplaatsing			

Figure 12.4: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.

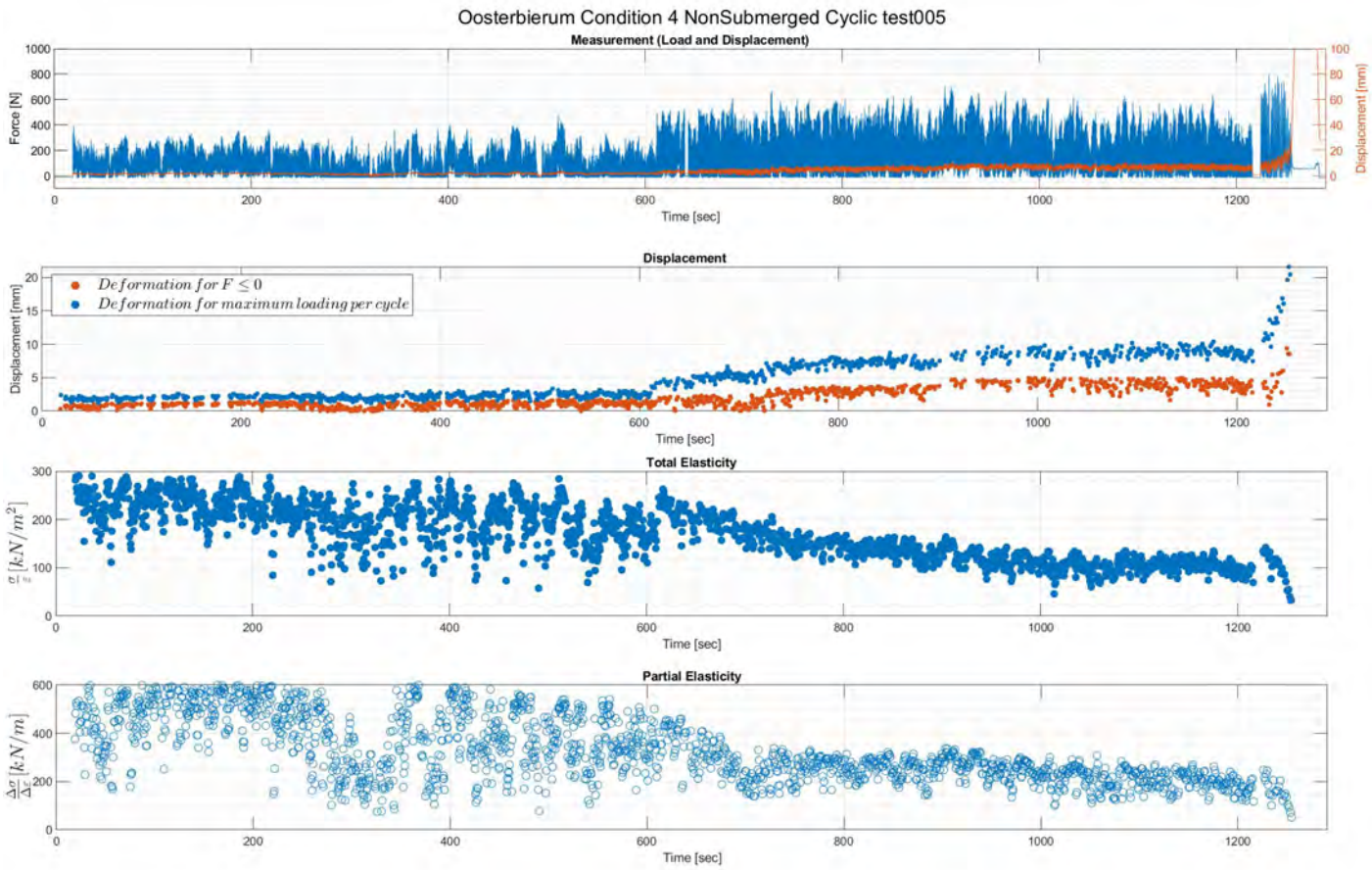


Development of displacement and elasticity are shown as function of number of cycles.

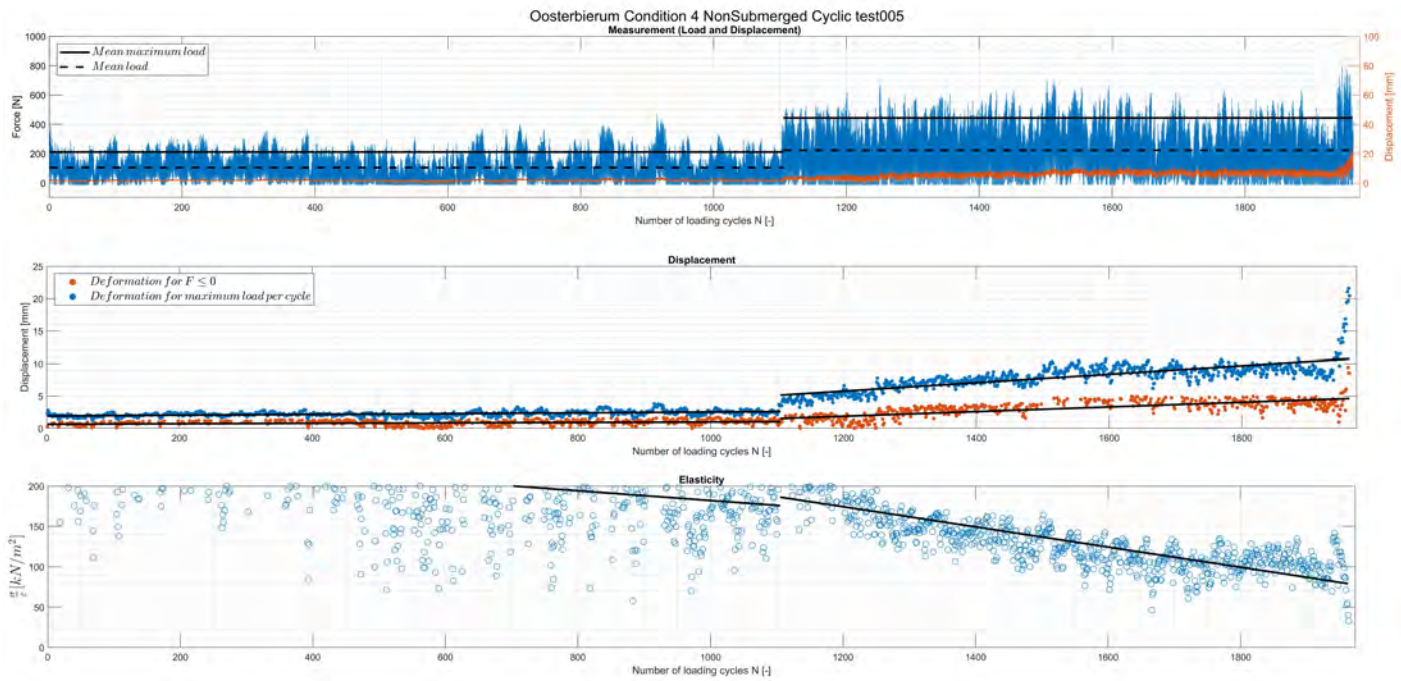
test005

		value 1	value 2	value 3	mean
Date		18-4-2019			
Mean load	$[N]$	1.05e+02	2.23e+02		1.64e+02
Mean maximum load	$[N]$	2.11e+02	4.43e+02		3.27e+02
Growth rate Plastic deformation	$\frac{\Delta U}{n}$ $[mm]$	3.43e-04	3.61e-03		
Growth rate Maximum deformation	$\frac{\Delta U}{n}$ $[mm]$	5.99e-04	6.53e-03		
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	56			
Sod Height	$[cm]$	12	8	0	10
Root Length	$[cm]$	1	4	0	2.5
Comments					

Figure 12.5: Pictures of tested grass sod.



Measurement of load and displacement and resulting elasticity.



Development of displacement and elasticity are shown as function of number of cycles.

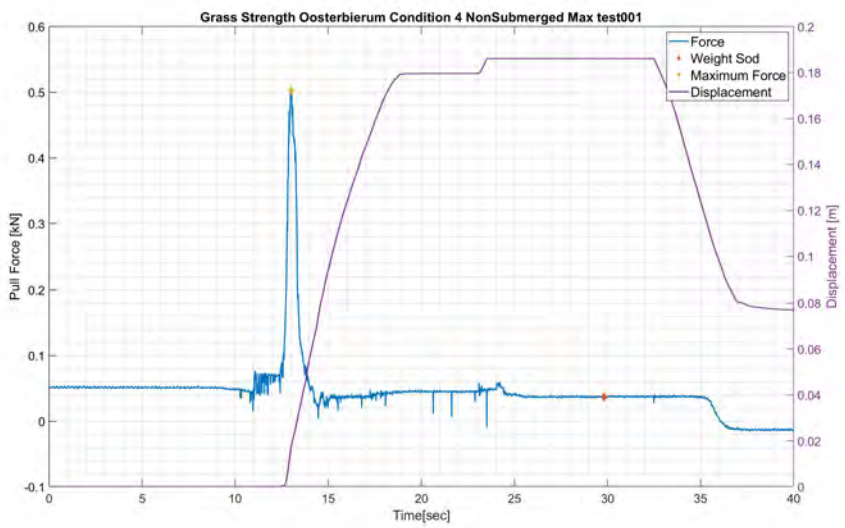
NonSubmerged Condition 4 Max

	F max $[N]$	Weight Sod $[kg]$	Width Sod $[cm]$	Mean Height Sod $[cm]$	Mean Root Length $[cm]$
test001	495	3.6	21	9.8	2.6
test002	539	2.5	21	10.0	3.5
test003	477	2.2	21	7.3	2.2
test004	451	2.7	21	8.2	2.4
test005	382	2.4	21	8.3	2.3
test006	625	2.8	21	9.2	2.4
test007	627	4.4	21	11.3	4.2
test008	538	4.3	21	8.4	4.0
test009	586	5.3	21	7.9	2.8
test010	974	5.5	21	8.8	1.4
test011	895	5.1	21	7.9	1.9
test012	917	5.0	21	11.4	1.4
Mean	686	4.1	21	9.1	2.6
Median	625	4.4	21	9	2
75th percentile	911	5.1	21	10	3
25th percentile	506	2.7	21	8	2

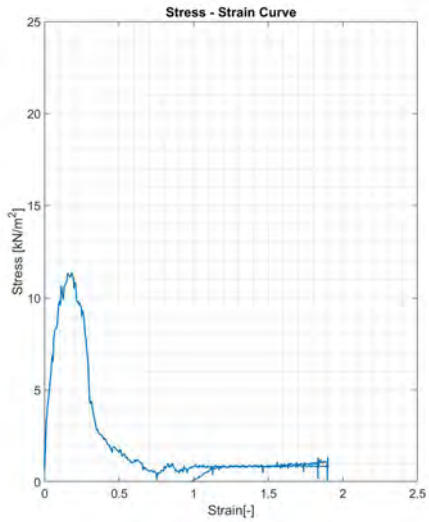
test001

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	494			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	36			
Sod Height	$[cm]$	13	9	5	9.8
Root Length	$[cm]$	1	3	5	2.6
Comments					

Figure 13.1: Pictures of tested grass sod.



Measurement of load and displacement

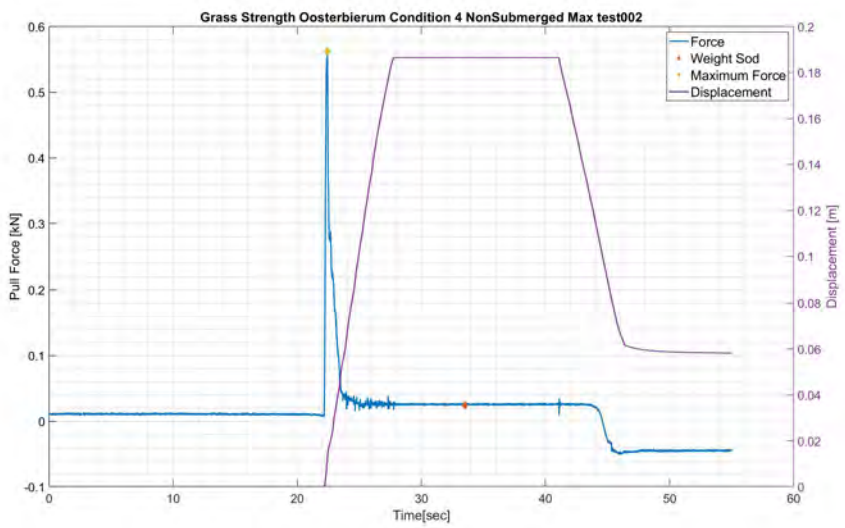


Stress - Strain relation.

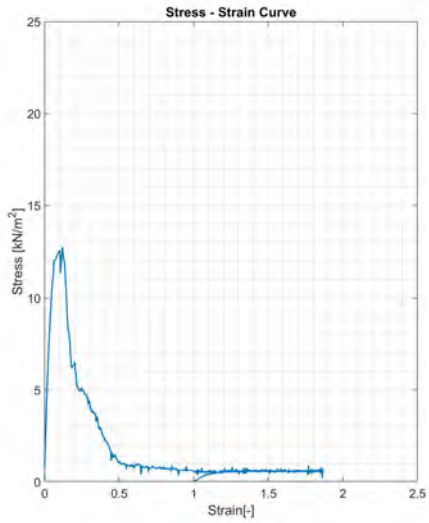
test002

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	539			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	25			
Sod Height	$[cm]$	11	9	0	10
Root Length	$[cm]$	2	5	0	3.5
Comments					

Figure 13.2: Pictures of tested grass sod.



Measurement of load and displacement

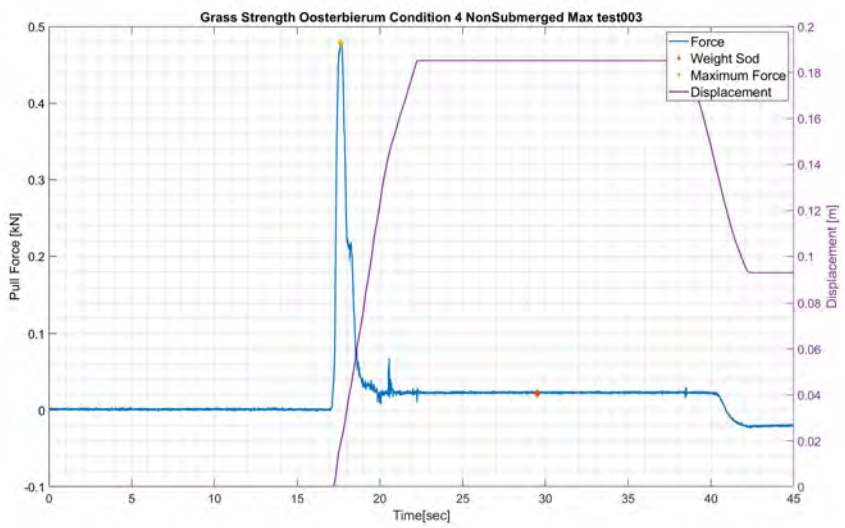


Stress - Strain relation.

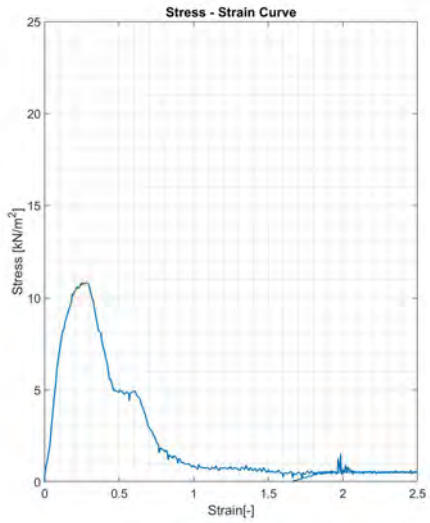
test003

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	476			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	22			
Sod Height	$[cm]$	10	9	3	7.3
Root Length	$[cm]$	1	2	3	2.2
Comments					

Figure 13.3: Pictures of tested grass sod.



Measurement of load and displacement

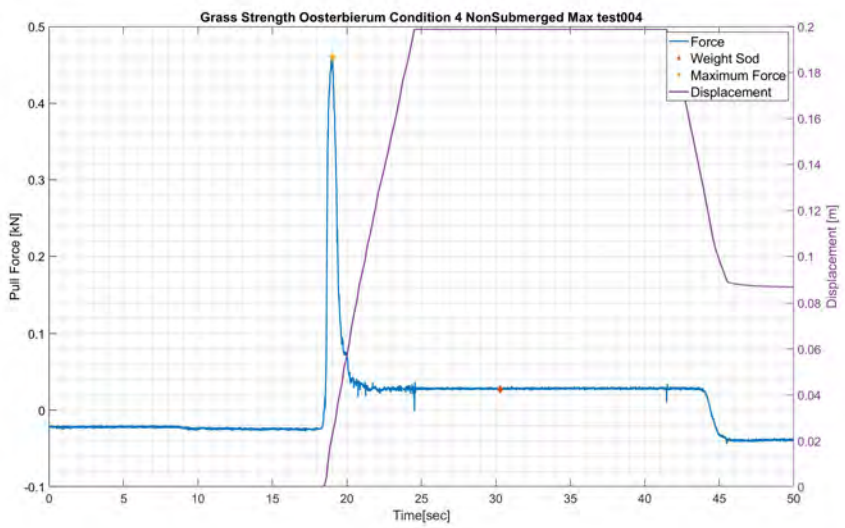


Stress - Strain relation.

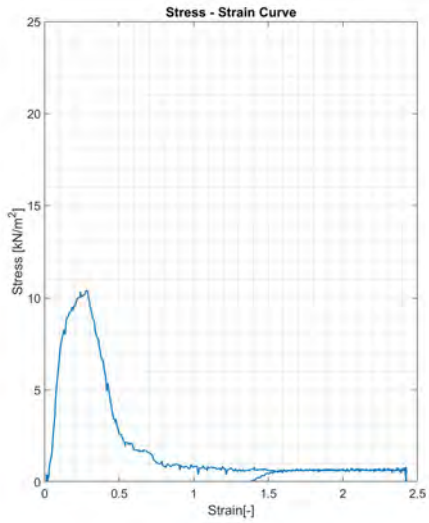
test004

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	452			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	27			
Sod Height	$[cm]$	11	9	4	8.2
Root Length	$[cm]$	2	2	4	2.4
Comments					

Figure 13.4: Pictures of tested grass sod.



Measurement of load and displacement

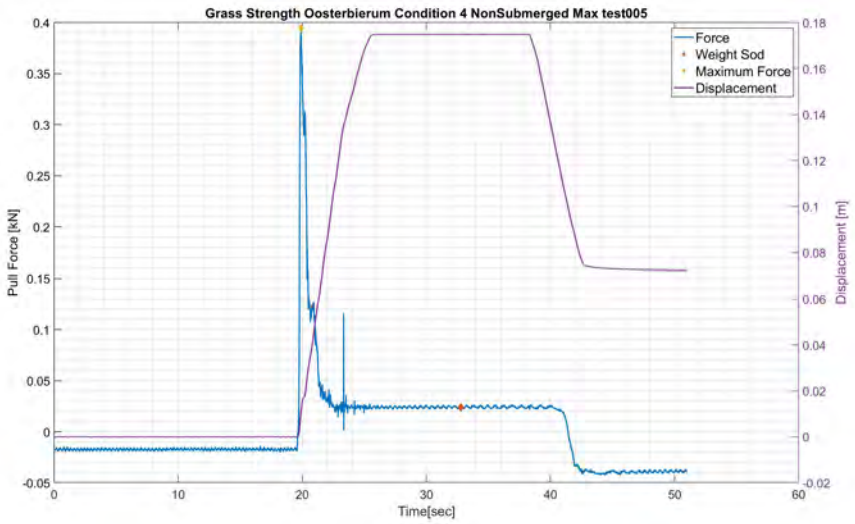


Stress - Strain relation.

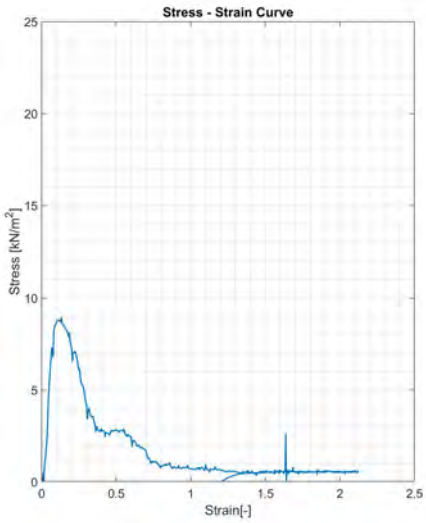
test005

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	383			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	24			
Sod Height	$[cm]$	11	9	4	8.3
Root Length	$[cm]$	1	2	4	2.3
Comments					

Figure 13.5: Pictures of tested grass sod.



Measurement of load and displacement

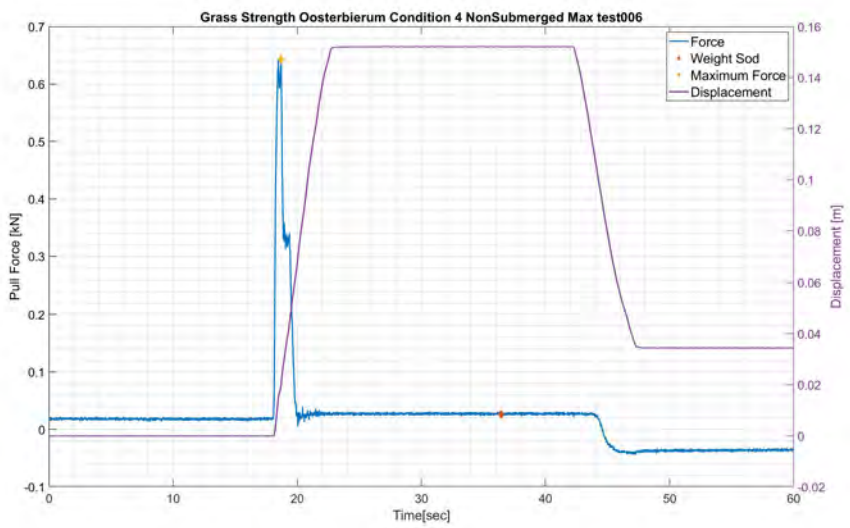


Stress - Strain relation.

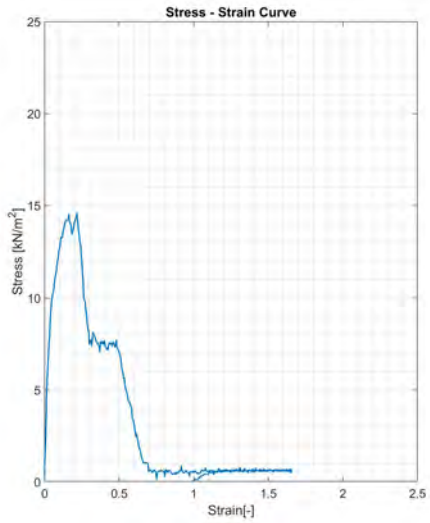
test006

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	625			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	28			
Sod Height	$[cm]$	11	10	5	9.2
Root Length	$[cm]$	1	2	5	2.4
Comments					

Figure 13.6: Pictures of tested grass sod.



Measurement of load and displacement

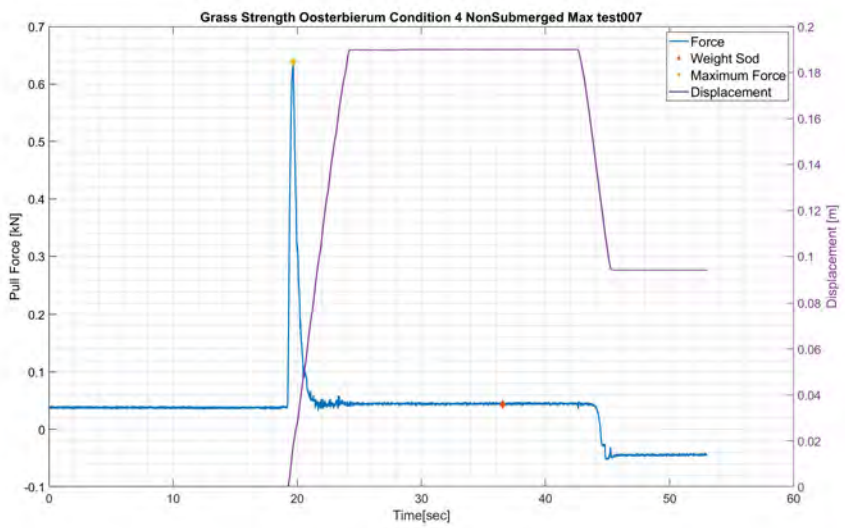


Stress - Strain relation.

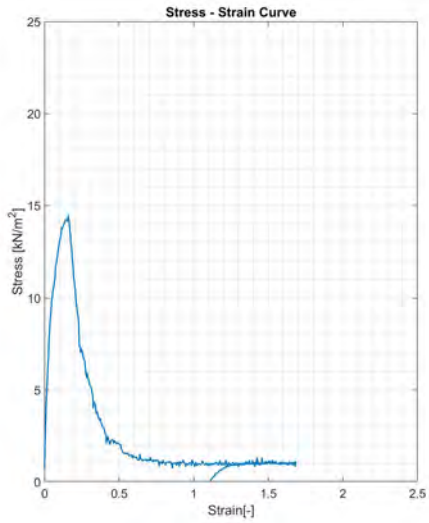
test007

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	626			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	44			
Sod Height	$[cm]$	13	12	5	11.3
Root Length	$[cm]$	4	4	5	4.2
Comments					

Figure 13.7: Pictures of tested grass sod.



Measurement of load and displacement

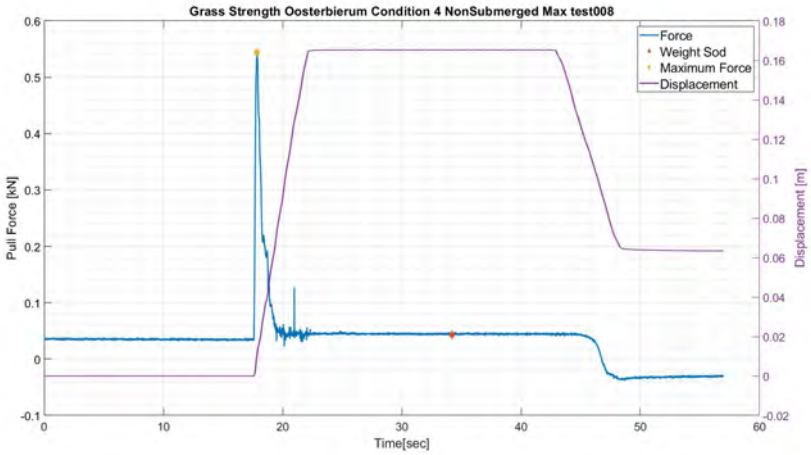


Stress - Strain relation.

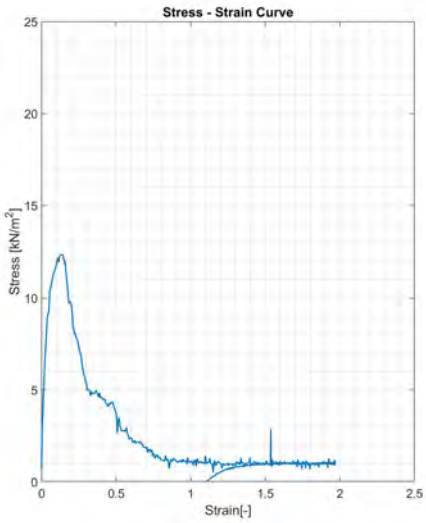
test008

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	535			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	43			
Sod Height	$[cm]$	11	9	5	8.4
Root Length	$[cm]$	3	4	5	4
Comments					

Figure 13.8: Pictures of tested grass sod.



Measurement of load and displacement

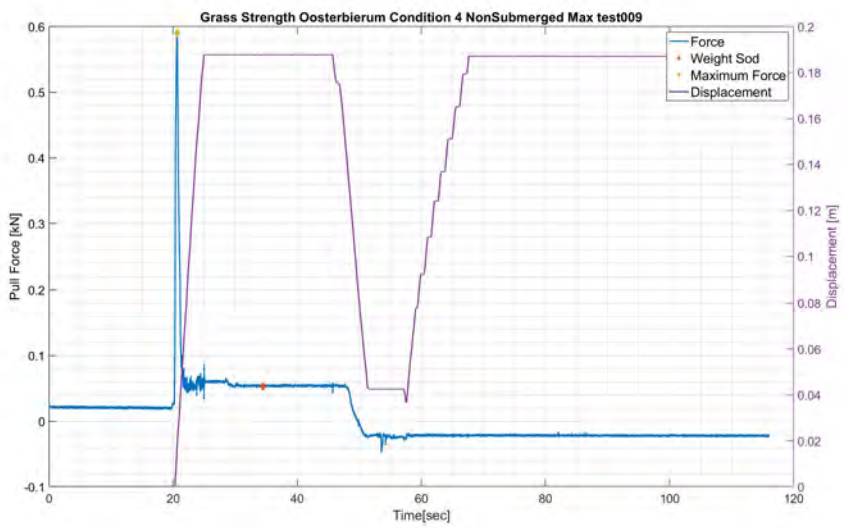


Stress - Strain relation.

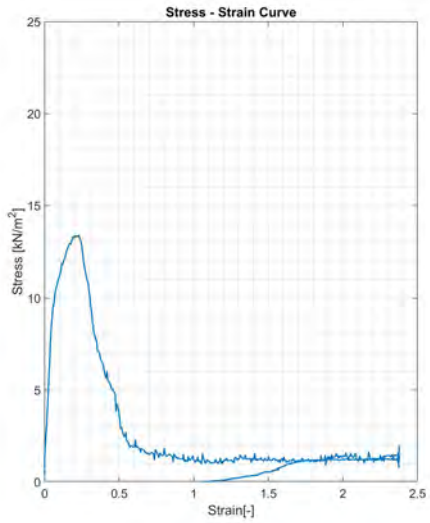
test009

		value 1	value 2	value 3	mean
Date		19-3-2019			
Maximum load	$[N]$	584			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	53			
Sod Height	$[cm]$	13	11	4	7.9
Root Length	$[cm]$	1	2	4	2.8
Comments					

Figure 13.9: Pictures of tested grass sod.



Measurement of load and displacement

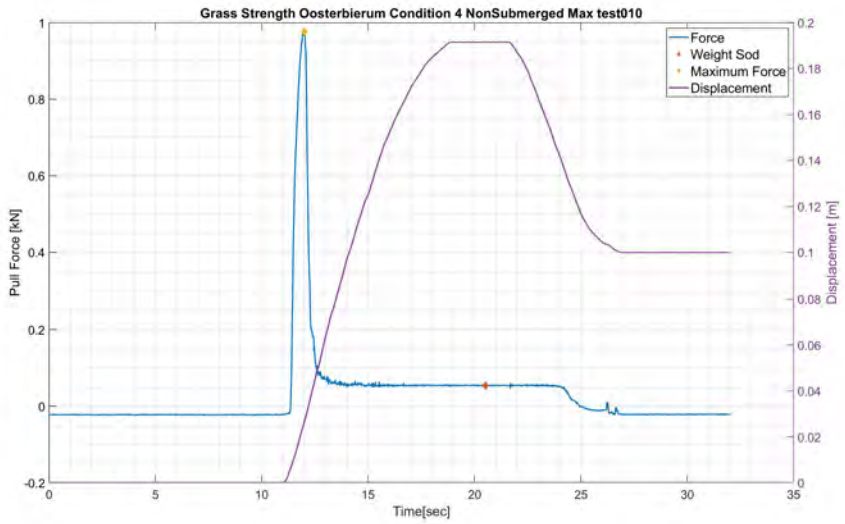


Stress - Strain relation.

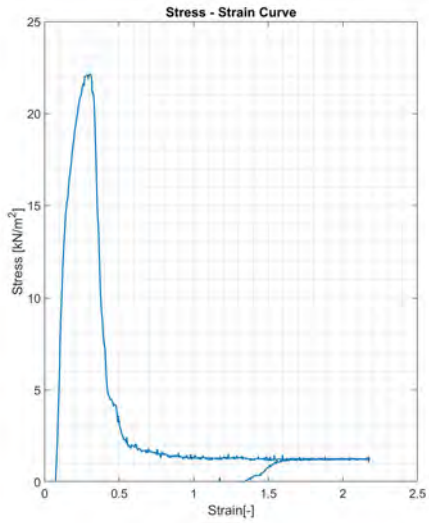
test010

		value 1	value 2	value 3	mean
Date		15-4-2019			
Maximum load	$[N]$	973			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	55			
Sod Height	$[cm]$	11	10	3	8.8
Root Length	$[cm]$	1	1	3	1.4
Comments					

Figure 13.10: Pictures of tested grass sod.



Measurement of load and displacement

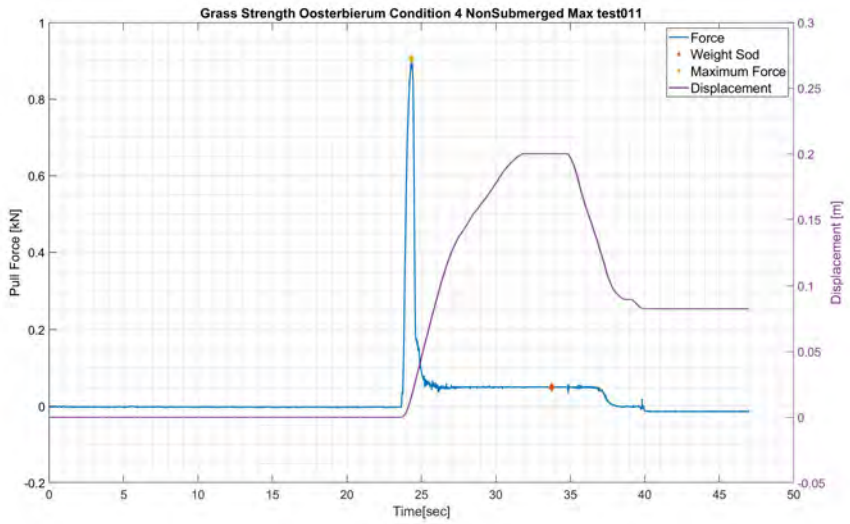


Stress - Strain relation.

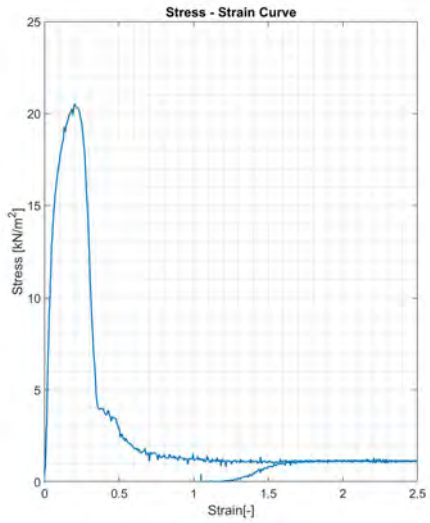
test011

		value 1	value 2	value 3	mean
Date		18-4-2019			
Maximum load	$[N]$	895			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	51			
Sod Height	$[cm]$	11	8	3	7.9
Root Length	$[cm]$	1	2	3	1.9
Comments					

Figure 13.11: Pictures of tested grass sod.



Measurement of load and displacement

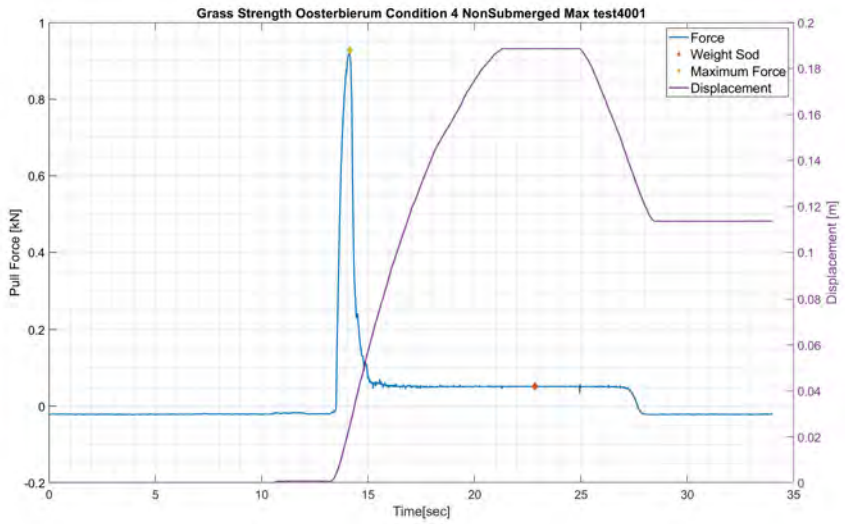


Stress - Strain relation.

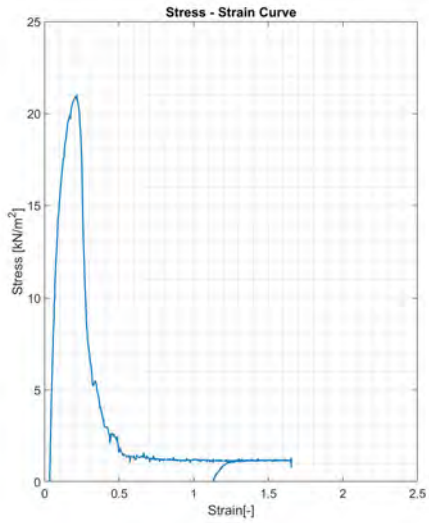
test012

		value 1	value 2	value 3	mean
Date		15-4-2019			
Maximum load	$[N]$	918			
Width Sod	$[cm]$	21			
Weight Sod	$[N]$	50			
Sod Height	$[cm]$	13	9	0	11.4
Root Length	$[cm]$	1	2	0	1.4
Comments					

Figure 13.12: Pictures of tested grass sod.



Measurement of load and displacement



Stress - Strain relation.