Could the capability of the current trenching equipment be improved with the use of different jet nozzle setups?

HZ university of applied science

Bachelor of engineering

Appendix

UNIVERSITY OF APPLIED SCIENCES

Boskalis

Creating new Horizons

TABLE OF CONTENT

APPENDIX A

Calculations

CALCULATIONS 5mm nozzle

Pre-determined parameters

$D_{nozzle} := 0.005\ m$

$D_{hose} := 0.025\ m$

$D_{inlet} := 0.015\ m$

$L_{hose} := 10\ m$

$Z_c := 0.12\ m$

$S_{uv} := 45\ kPa$

$\rho := 1000\ \frac{kg}{m^3}$

$k := 0.0003\ mm$

$V := 0.000001\ \frac{m}{s^2}$

$g := 9.81\ \frac{m}{s^2}$

$V_{trench} := 0.0183\ \frac{m}{s}$

$V_{ref} := 1\ \frac{m}{s}$

$\mu_{nozzle} := 0.88$

Nozzle pressure with cutting depth of 0.12 m

$$P_{nozzle} := \frac{Z_c \cdot S_{uv} \cdot \left(\frac{V_{trench}}{V_{ref}}\right)^{0.2}}{0.2 \cdot D_{nozzle}} = 24.26\ bar$$

Velocity nozzle exit

$$u_{nozzle} := \sqrt{\left(\frac{P_{nozzle}}{\frac{1}{2} \cdot \rho}\right)} = 69.656\ \frac{m}{s}$$

Discharge through nozzle per second

$$Q_{nozzle} := \mu_{nozzle} \cdot \frac{1}{4} \cdot \pi \cdot D_{nozzle}{}^2 \cdot u_{nozzle} = 0.0012\ \frac{m^3}{s}$$

Area hose & inlet

$$A_{hose} := \pi \cdot \left(\frac{D_{hose}}{2}\right)^2 = 0.00049\ m^2$$

$$A_{inlet} := \pi \cdot \left(\frac{D_{inlet}}{2}\right)^2 = 0.00018\ m^2$$

Velocity through hose & inlet

$$U_{hose} := \frac{Q_{nozzle}}{A_{hose}} = 2.452\ \frac{m}{s}$$

$$U_{inlet} := \frac{Q_{nozzle}}{A_{inlet}} = 6.811\ \frac{m}{s}$$

Lambda

$$\lambda := \frac{0.25}{\left(\log\left(3.7 \cdot \frac{D_{hose}}{k}\right)\right)^2} = 0.008$$

ksi reduction factor

$\xi_1 := 0.07$ "Bend 1/2/3"

$\xi_2 := 1.15$ "kin 90"

$\xi_3 := 0.17$ "reducer"

$\xi_{total} := 3 \cdot \xi_1 + \xi_2 + \xi_3 = 1.53$

Presure loss in hose

$$Hl_{hose} := \left(\xi_{total} + \lambda \cdot \frac{L_{hose}}{D_{hose}}\right) \cdot \frac{1}{2} \cdot \rho \cdot U_{hose}{}^{2} = 0.1458\ \mathbf{bar}$$

Pressure loss at the nozzle

$$\xi_{nozzle} := 0.125$$

$$Hl_{nozzle} := \left(\xi_{nozzle}\right) \cdot \frac{1}{2} \cdot \rho \cdot U_{inlet}{}^{2} = 0.029\ \mathbf{bar}$$

Total pressure loss

$$Hl_{total} := Hl_{hose} + Hl_{nozzle} = 0.175\ \mathbf{bar}$$

Total necessary presure in pump

$$p_{total} := Hl_{hose} + Hl_{nozzle} + P_{nozzle} = 24.434\ \mathbf{bar}$$

Pressure head

Necessary pressure head to jet through 0.12 m of clay

$$y := \frac{p_{total}}{\rho \cdot g} = 249.076\ \mathbf{m}$$

Cavity width

$$k_1 := 77$$

$$sod := 0.010\ \mathbf{m}$$

$$S_{dr} := \sqrt{\frac{k_1}{2}} \cdot D_{nozzle} = 0.031\ \mathbf{m}$$

$$n_1 := \frac{sod}{S_{dr}} = 0.322$$

$$W_c := D_{nozzle} \cdot \left(1 + n_1\right) = 0.007\ \mathbf{m}$$

Forces acting on the plough during trenching

Parameters

$y := 15000 \frac{N}{m^3}$ $\quad w := 0.01\ m$ $\quad N_y := 0.0$

$c := 45000\ Pa$ $\quad N_c := 7.9$

$d := 0.065\ m$ $\quad q := y \cdot d = 975\ Pa$ $\quad N_a := 0.62$

$b := 0.04\ m$ $\quad c_a := 15000\ Pa$

Removed area

The removed area is the area that is removed by the jet nozzle in front of the plough.

$$A := d \cdot W_c = 0.00043\ m^2$$

Forward failure regime

$$P_f := y \cdot d^2 \cdot b \cdot N_y + c \cdot (d \cdot b - A) \cdot N_c + c_a \cdot (d \cdot b - A) \cdot N_a + q \cdot (d \cdot b - A) \cdot N_a = 793.017\ N$$

Sidewards failure regime

$$P_s := y \cdot \left(d + \frac{q}{y}\right)^2 \cdot w \cdot N_y + c \cdot w \cdot d \cdot N_c = 231.075\ N$$

CALCULATIONS 10mm NOZZLE

Pre-determined parameters

$D_{nozzle} := 0.010\ m$
$D_{hose} := 0.025\ m$
$D_{inlet} := 0.015\ m$
$L_{hose} := 10\ m$
$Z_c := 0.12\ m$
$S_{uv} := 45\ kPa$

$\rho := 1000\ \frac{kg}{m^3}$
$k := 0.0003\ mm$
$V := 0.000001\ \frac{m}{s^2}$
$g := 9.81\ \frac{m}{s^2}$

$V_{trench} := 0.0183\ \frac{m}{s}$
$V_{ref} := 1\ \frac{m}{s}$
$\mu_{nozzle} := 0.88$

Nozzle pressure with cutting depth of 0.12m

$$P_{nozzle} := \frac{Z_c \cdot S_{uv} \cdot \left(\frac{V_{trench}}{V_{ref}}\right)^{0.2}}{0.2 \cdot D_{nozzle}} = 12.13\ bar$$

Velocity nozzle exit

$$u_{nozzle} := \sqrt{\left(\frac{P_{nozzle}}{\frac{1}{2} \cdot \rho}\right)} = 49.254\ \frac{m}{s}$$

Discharge through nozzle per second

$$Q_{nozzle} := \mu_{nozzle} \cdot \frac{1}{4} \cdot \pi \cdot D_{nozzle}{}^2 \cdot u_{nozzle} = 0.003\ \frac{m^3}{s}$$

Area hose & inlet

$$A_{hose} := \pi \cdot \left(\frac{D_{hose}}{2}\right)^2 = 0.00049\ m^2$$

$$A_{inlet} := \pi \cdot \left(\frac{D_{inlet}}{2}\right)^2 = 0.000176715\ m^2$$

Velocity through hose & inlet

$$U_{hose} := \frac{Q_{nozzle}}{A_{hose}} = 6.935\ \frac{m}{s}$$

$$U_{inlet} := \frac{Q_{nozzle}}{A_{inlet}} = 19.264\ \frac{m}{s}$$

Lambda

$$\lambda := \frac{0.25}{\left(\log\left(3.7 \cdot \frac{D_{hose}}{k}\right)\right)^2} = 0.008$$

ksi reduction factor

$\xi_1 := 0.07$ “Bend 1/2/3”
$\xi_2 := 1.15$ “kin 90”
$\xi_3 := 0.17$ “reducer”
$\xi_{total} := 3 \cdot \xi_1 + \xi_2 + \xi_3 = 1.53$

Presure loss in hose

$$Hl_{hose} := \left(\xi_{total} + \lambda \cdot \frac{L_{hose}}{D_{hose}}\right) \cdot \frac{1}{2} \cdot \rho \cdot U_{hose}^{2} = 1.166 \ \textbf{bar}$$

Pressure loss at the nozzle

$$\xi_{nozzle} := 0.125$$

$$Hl_{nozzle} := \left(\xi_{nozzle}\right) \cdot \frac{1}{2} \cdot \rho \cdot U_{inlet}^{2} = 0.232 \ \textbf{bar}$$

Total pressure loss

$$Hl_{total} := Hl_{hose} + Hl_{nozzle} = 1.398 \ \textbf{bar}$$

Total necessary presure in pump

$$p_{total} := Hl_{hose} + Hl_{nozzle} + P_{nozzle} = 13.528 \ \textbf{bar}$$

Pressure head

Necassary pressure head to jet through 0.12 m of clay

$$y := \frac{p_{total}}{\rho \cdot g} = 137.898 \ \textbf{m}$$

Cavity width

$$k_1 := 77$$
$$sod := 0.010 \ \textbf{m}$$

$$S_{dr} := \sqrt{\frac{k_1}{2}} \cdot D_{nozzle} = 0.062 \ \textbf{m}$$

$$n_1 := \frac{sod}{S_{dr}} = 0.161$$

$$W_c := D_{nozzle} \cdot \left(1 + n_1\right) = 0.012 \ \textbf{m}$$

Forces acting on the plough during trenching

Parameters

$y := 15000 \frac{N}{m^3}$ $w := 0.01\ m$ $N_y := 0.0$

$c := 45000\ Pa$ $N_c := 7.9$

$d := 0.065\ m$ $q := y \cdot d = 975\ Pa$ $N_a := 0.62$

$b := 0.04\ m$ $c_a := 15000\ Pa$

Removed area

The removed area is the area that is removed by the jet nozzle in front of the plough.

$$A := d \cdot W_c = 0.00075\ m^2$$

Forward failure regime

$$P_f := y \cdot d^2 \cdot b \cdot N_y + c \cdot (d \cdot b - A) \cdot N_c + c_a \cdot (d \cdot b - A) \cdot N_a + q \cdot (d \cdot b - A) \cdot N_a = 674.26\ N$$

Sidewards failure regime

$$P_s := y \cdot \left(d + \frac{q}{y}\right)^2 \cdot w \cdot N_y + c \cdot w \cdot d \cdot N_c = 231.075\ N$$

CALCULATIONS 14mm NOZZLE

Pre-determined Parameters

$D_{nozzle} := 0.014\ m$

$D_{hose} := 0.025\ m$

$D_{inlet} := 0.014\ m$

$L_{hose} := 10\ m$

$Z_c := 0.12\ m$

$S_{uv} := 45\ kPa$

$\rho := 1000\ \frac{kg}{m^3}$

$k := 0.0003\ mm$

$V := 0.000001\ \frac{m}{s^2}$

$g := 9.81\ \frac{m}{s^2}$

$V_{trench} := 0.0183\ \frac{m}{s}$

$V_{ref} := 1\ \frac{m}{s}$

$\mu_{nozzle} := 0.88$

Nozzle pressure with cutting depth of 0.12m

$$P_{nozzle} := \frac{Z_c \cdot S_{uv} \cdot \left(\frac{V_{trench}}{V_{ref}}\right)^{0.2}}{0.2 \cdot D_{nozzle}} = 8.664\ bar$$

Velocity "nozzle exit"

$$u_{nozzle} := \sqrt{\left(\frac{P_{nozzle}}{\frac{1}{2} \cdot \rho}\right)} = 41.627\ \frac{m}{s}$$

Discharge through nozzle per hour

$$Q_{nozzle} := \mu_{nozzle} \cdot \frac{1}{4} \cdot \pi \cdot D_{nozzle}^{\ 2} \cdot u_{nozzle} = 20.301\ \frac{m^3}{hr}$$

Area hose & inlet

$$A_{hose} := \pi \cdot \left(\frac{D_{hose}}{2}\right)^2 = 490.874\ mm^2$$

$$A_{inlet} := \pi \cdot \left(\frac{D_{inlet}}{2}\right)^2 = 153.938\ mm^2$$

Velocity through hose & inlet

$$U_{hose} := \frac{Q_{nozzle}}{A_{hose}} = 11.488\ \frac{m}{s}$$

$$U_{inlet} := \frac{Q_{nozzle}}{A_{inlet}} = 36.632\ \frac{m}{s}$$

Lambda

$$\lambda := \frac{0.25}{\left(\log\left(3.7 \cdot \frac{D_{hose}}{k}\right)\right)^2} = 0.008$$

ksi reduction factor

$\xi_1 := 0.07$ "Bend 1/2/3"

$\xi_2 := 1.15$ "kin 90"

$\xi_3 := 0.17$ "reducer"

$\xi_{total} := 3 \cdot \xi_1 + \xi_2 + \xi_3 = 1.53$

Presure loss in hose

$$Hl_{hose} := \left(\xi_{total} + \lambda \cdot \frac{L_{hose}}{D_{hose}}\right) \cdot \frac{1}{2} \cdot \rho \cdot U_{hose}^{\;2} = 3.1996 \; \mathbf{bar}$$

Pressure loss at the nozzle

$$\xi_{nozzle} := 0.125$$

$$Hl_{nozzle} := \left(\xi_{nozzle}\right) \cdot \frac{1}{2} \cdot \rho \cdot U_{inlet}^{\;2} = 0.839 \; \mathbf{bar}$$

Total pressure loss

$$Hl_{total} := Hl_{hose} + Hl_{nozzle} = 4.038 \; \mathbf{bar}$$

Total necessary presure in pump

$$p_{total} := Hl_{hose} + Hl_{nozzle} + P_{nozzle} = 12.702 \; \mathbf{bar}$$

Necessary pressure head

$$y := \frac{p_{total}}{\rho \cdot g} = 129.485 \; \mathbf{m}$$

Cavity width

$$k_1 := 77$$

$$sod := 0.010 \; \mathbf{m}$$

$$S_{dr} := \sqrt{\frac{k_1}{2}} \cdot D_{nozzle} = 0.087 \; \mathbf{m}$$

$$n_1 := \frac{sod}{S_{dr}} = 0.115$$

$$W_c := D_{nozzle} \cdot \left(1 + n_1\right) = 0.016 \; \mathbf{m}$$

Forces acting on the plough during trenching

Parameters

$y := 15000 \frac{N}{m^3}$ $\quad w := 0.01\ m$ $\quad N_y := 0.0$

$c := 45000\ Pa$ $\quad N_c := 7.9$

$d := 0.065\ m$ $\quad q := y \cdot d = 975\ Pa$ $\quad N_a := 0.62$

$b := 0.04\ m$ $\quad c_a := 15000\ Pa$

Removed area

The removed area is the area that is removed by the jet nozzle in front of the plough.

$$A := d \cdot W_c = 0.00101\ m^2$$

Forward failure regime

$$P_f := y \cdot d^2 \cdot b \cdot N_y + c \cdot (d \cdot b - A) \cdot N_c + c_a \cdot (d \cdot b - A) \cdot N_a + q \cdot (d \cdot b - A) \cdot N_a = 579.255\ N$$

Sidewards failure regime

$$P_s := y \cdot \left(d + \frac{q}{y}\right)^2 \cdot w \cdot N_y + c \cdot w \cdot d \cdot N_c = 231.075\ N$$

CALCULATIONS 45mm NOZZLE

Pre-determined parameters

$D_{nozzle} := 0.045\ \mathbf{m}$

$D_{hose} := 0.025\ \mathbf{m}$

$S_{uv} := 40\ \mathbf{kPa}$

$P_{jet} := 11.849\ \mathbf{bar}$

$\mu_{nozzle} := 0.88$

$N_{bc} := 5.14$

$\rho := 1000\ \frac{\mathbf{kg}}{\mathbf{m}^3}$

$V_{trench} := 0.017\ \frac{\mathbf{m}}{\mathbf{s}}$

$V_{ref} := 1\ \frac{\mathbf{m}}{\mathbf{s}}$

To compare the effects of a wide rotation nozzle and a small rotating nozzle the same P_{jet} necessary to jet through 0.12m of clay with a 10mm nozlee will be used with the 45mm nozzle. So that a direct comparisson can be used.

Minimum required velocity

$$U_{min} := \sqrt{\frac{2 \cdot N_{bc} \cdot S_{uv}}{\rho}} = 20.278\ \frac{\mathbf{m}}{\mathbf{s}}$$

Cavity area 10mm nozzle

Area 10mm nozzle

$W_{c10} := 0.012\ \mathbf{m}$

$Z_{c10} := 0.12\ \mathbf{m}$

$$A_{10} := W_{c10} \cdot Z_{c10} = 0.00144\ \mathbf{m}^2$$

Cavity width

$k_1 := 77$

$sod := 0.010\ \mathbf{m}$

$$S_{dr} := \sqrt{\frac{k_1}{2}} \cdot D_{nozzle} = 0.279\ \mathbf{m}$$

$$n_1 := \frac{sod}{S_{dr}} = 0.036$$

$$W_c := D_{nozzle} \cdot \left(1 + n_1\right) = 0.047\ \mathbf{m}$$

Cavity depth 45mm nozzle

$$Z_c := \frac{A_{10}}{W_c} = 0.031\ \mathbf{m}$$

Forces acting on the plough during trenching

Parameters

$y := 15000 \ \frac{N}{m^3}$ $w := 0.01 \ m$ $N_y := 0.0$

$c := 40000 \ Pa$ $N_c := 7.9$

$d := 0.065 \ m$ $q := y \cdot d = 975 \ Pa$ $N_a := 0.62$

$b := 0.04 \ m$ $c_a := 15000 \ Pa$

Removed area

The removed area is the area that is removed by the jet nozzle in front of the plough.

$$A := Z_c \cdot W_c = 0.00144 \ m^2$$

Forward failure regime

$$P_f := y \cdot d^2 \cdot b \cdot N_y + c \cdot (d \cdot b - A) \cdot N_c + c_a \cdot (d \cdot b - A) \cdot N_a + q \cdot (d \cdot b - A) \cdot N_a = 378.049 \ N$$

Sidewards failure regime

$$P_s := y \cdot \left(d + \frac{q}{y}\right)^2 \cdot w \cdot N_y + c \cdot w \cdot d \cdot N_c = 205.4 \ N$$

APPENDIX B

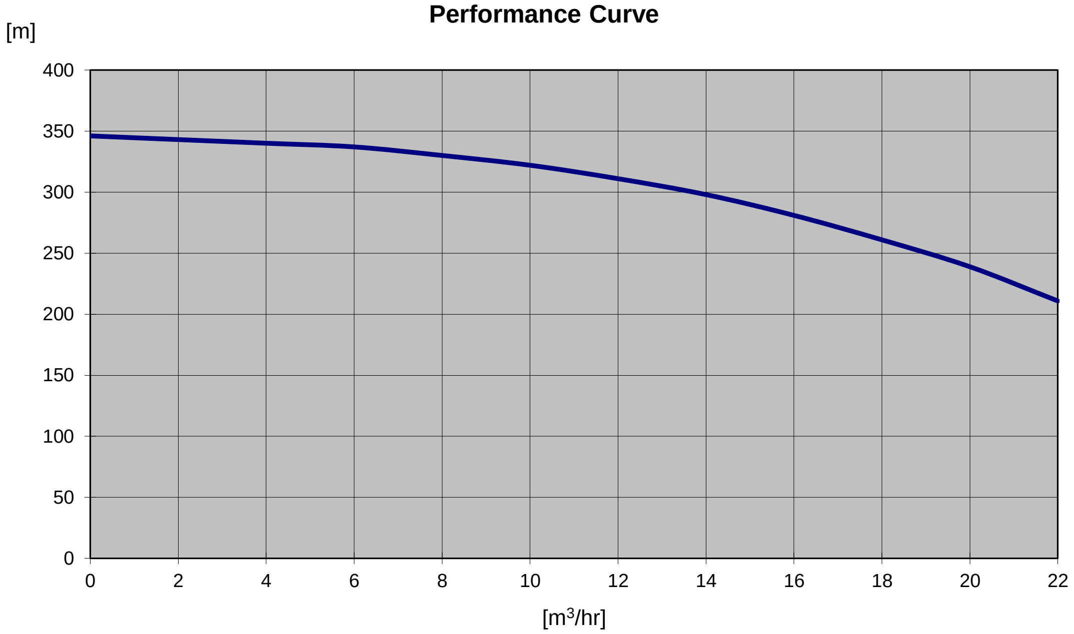
Pump specifications

INFOSHEET

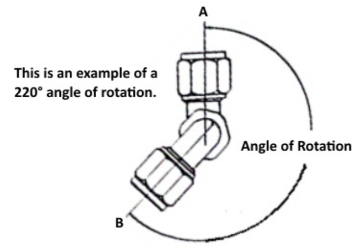
200/50
1” elektrisch op skid

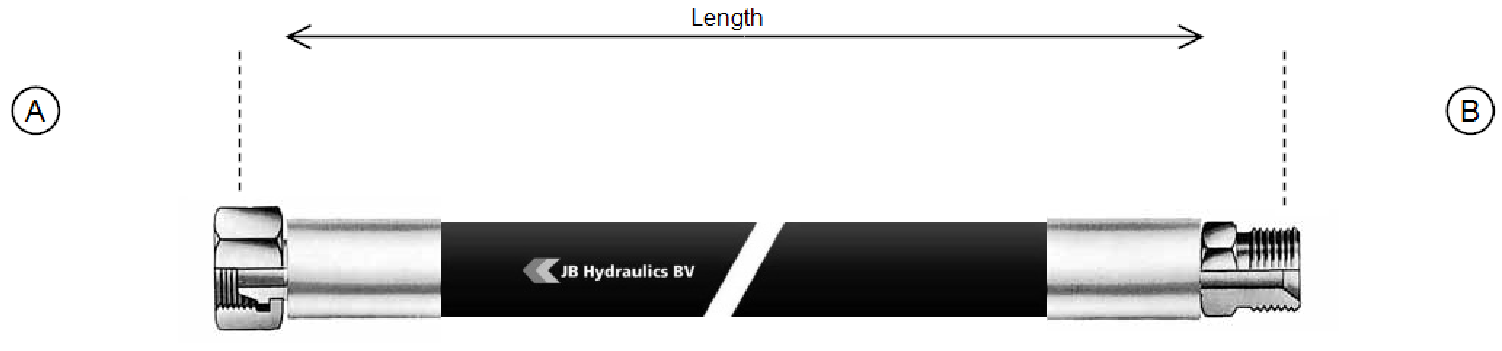
Motor	:	3 fasen draaistroom 400V / 50Hz
Pomp	:	KSB Multitec B32/13C-2.1
Vermogen	:	22 kW bij 2950 rpm
Gewicht	:	350 kg
Afmetingen	:	L=1,9 B=0,75 H=1,2 [mtr.]
Aansluitingen	:	zuig=2” pers=1¼ ”
Voorzieningen	:	- centraal hijsoog - automatische ster-driehoek-schakeling - fase-beveiliging, - 63A 5 polige stekker
Bijzonderheden	:	Motor Ex de IIC T4

Performance Curve



JB Hydraulics BV





Assembly number : H-116556

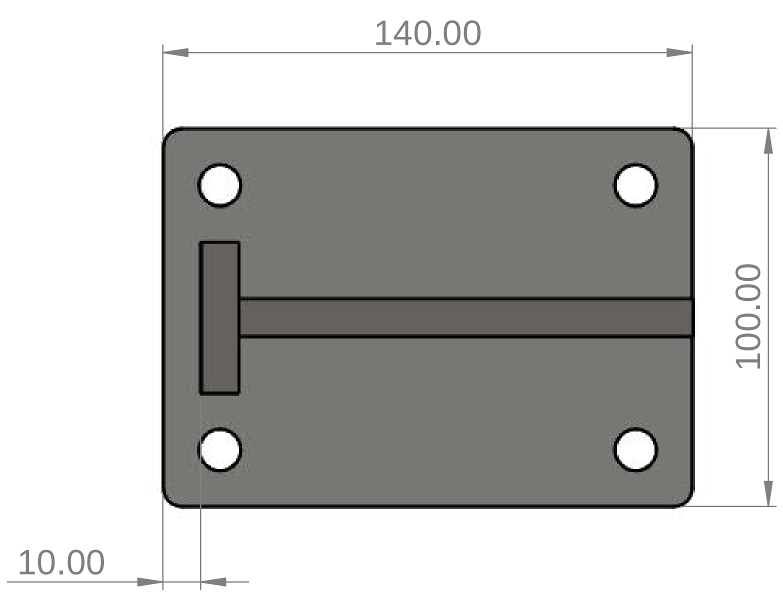
Hose type	:	20-111-25	Slimline 121 (1 SC) WP 88 Bar DN25 - 1"
Hose size	:		DN25 - 1"
Length (mm)	:	-	10000
Protection	:	-	-
Coupling A	:	30-301-16-16	DKOR-1" - BSPP Female 60° cone
Coupling B	:	30-302-16-16	AGR-1" - BSPP Male parallel 60° flare
Material	:		Steel
Angle of rotation	:		0°
Reference	:	-	
Description JB	:	111-25/10000/301-16/302-16	

APPENDIX C

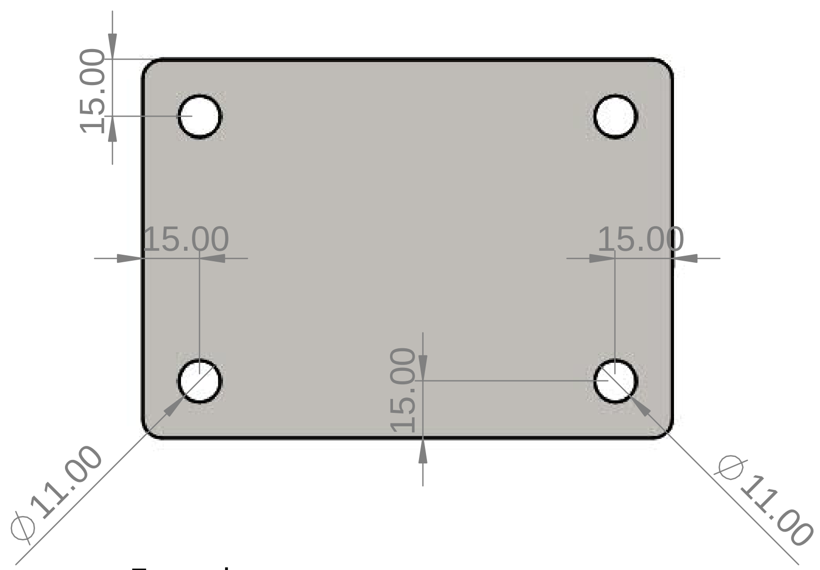
Drawings experimental setup

Drawing list

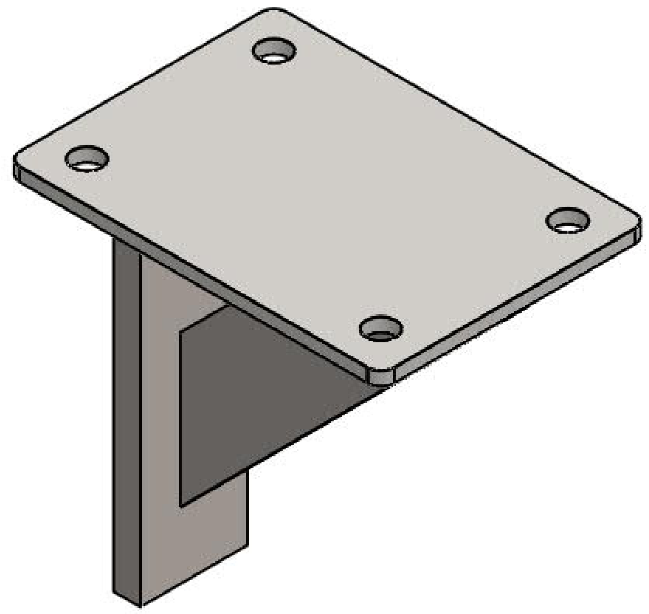
Drawing NO.	***Drawing name***	***Status***	***Date***
1.1	Plough	Final	01-05-2019
1.2	Nozzle holder	Final	01-05-2019
1.3	Clay box	Final	01-05-2019
1.4	Guidance rail	Final	01-05-2019
1.5	Holding box	Final	01-05-2019
1.6	Guidance cart	Final	01-05-2019
2.1	Total assembly	Final	01-05-2019

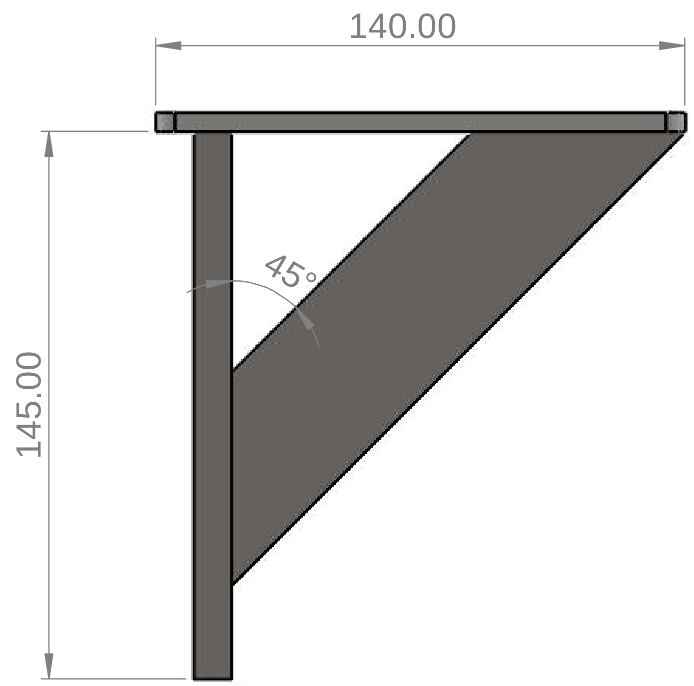


Bottom view

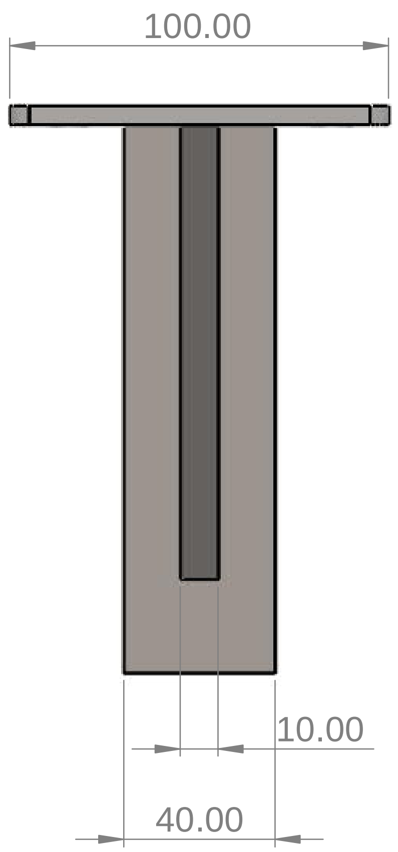


Top view

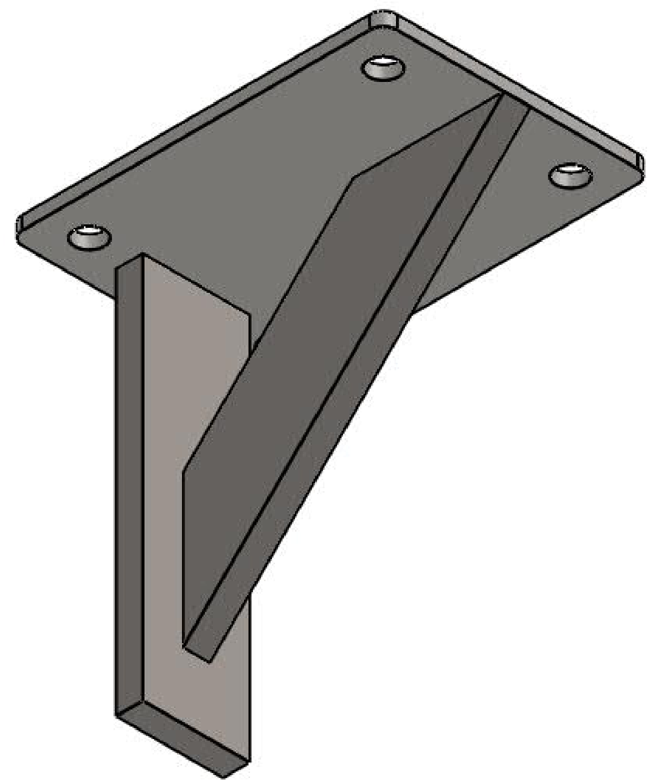




Left sideview



Backside view



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Mark Roos		01-05
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Plough

MATERIAL: Steel: S355

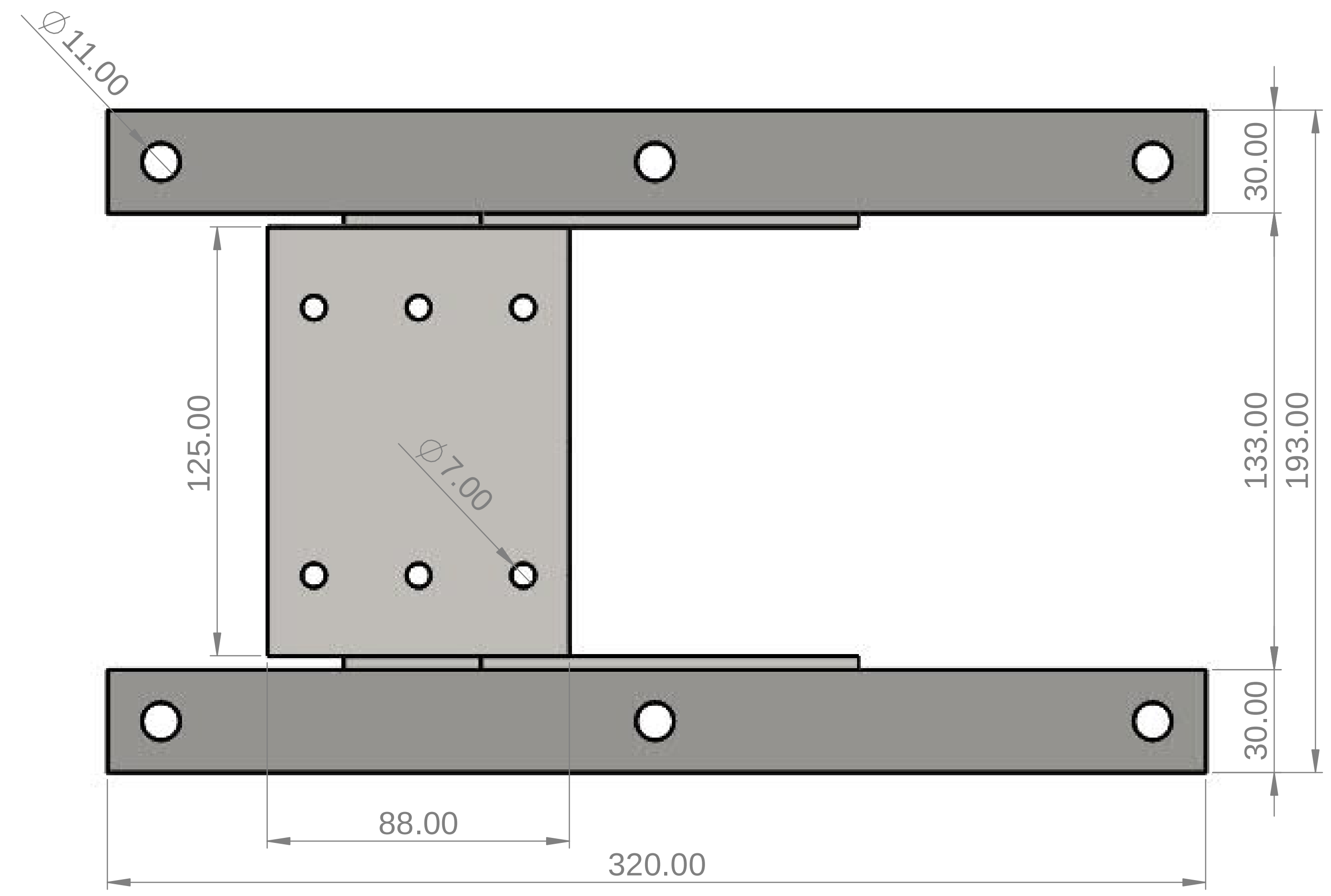
DWG NO. 1.1

A3

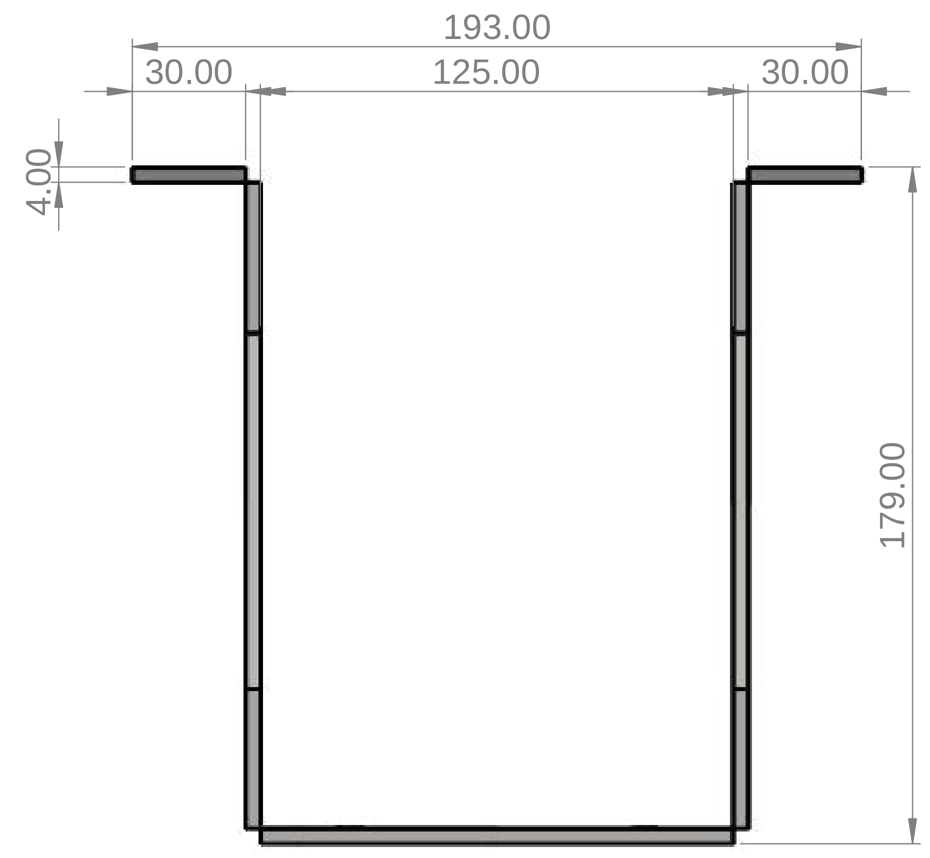
WEIGHT:

SCALE:1:2

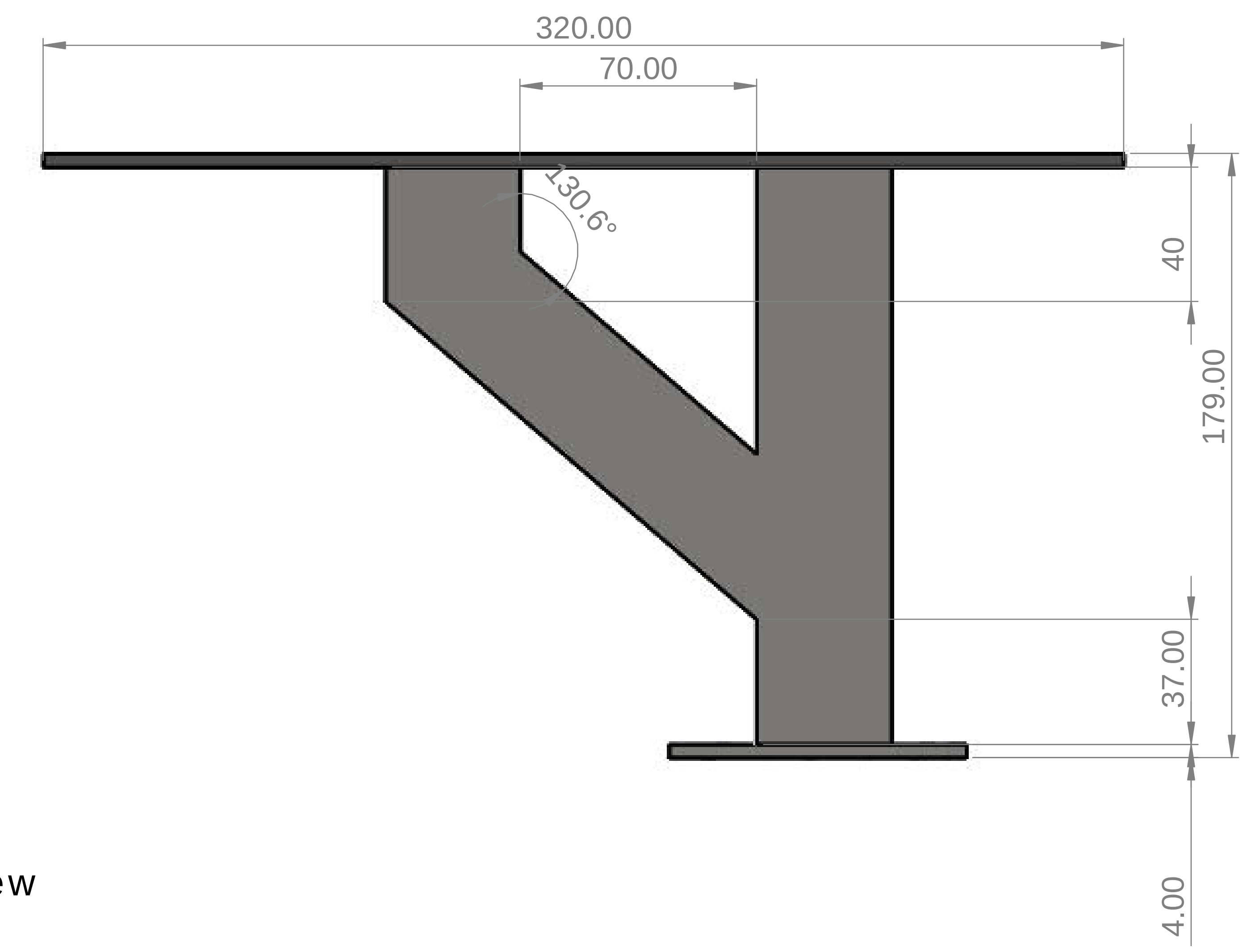
SHEET 1 OF 1



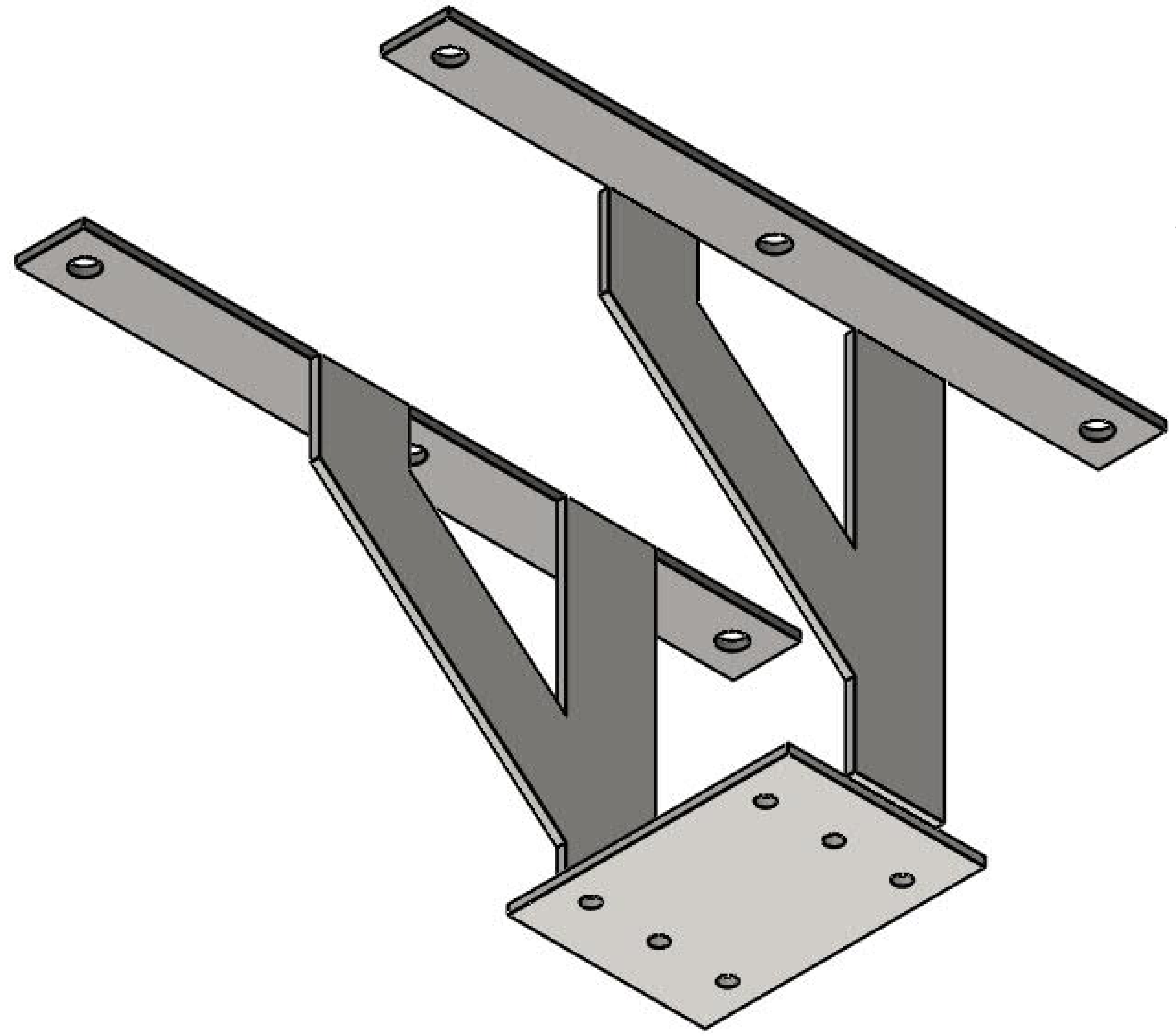
Top view



Front view

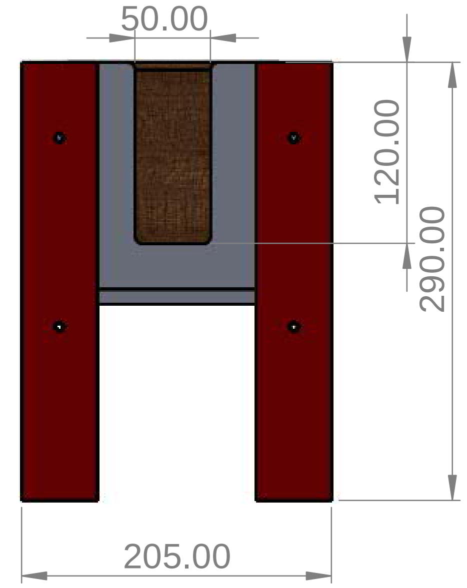


Side view

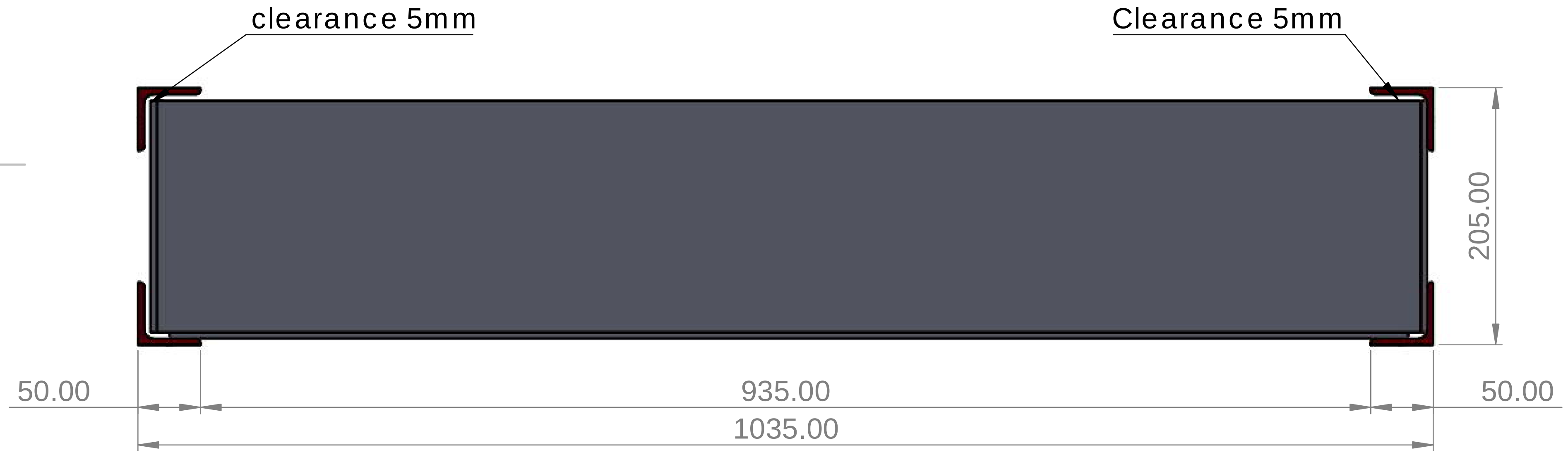


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE	TITLE: Nozzleholder	
DRAWN	Mark Roos		01-05		
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Steel S355	DWG NO. 1.2	A2
			WEIGHT:	SCALE:1:2	SHEET 1 OF 1

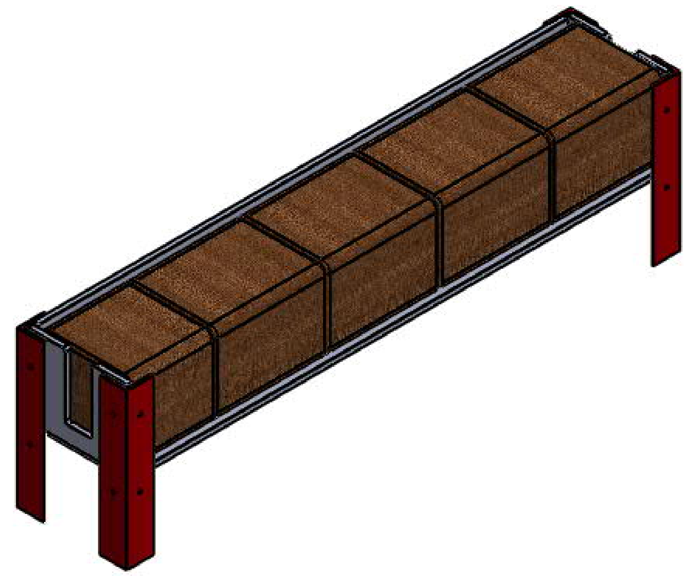
Front view



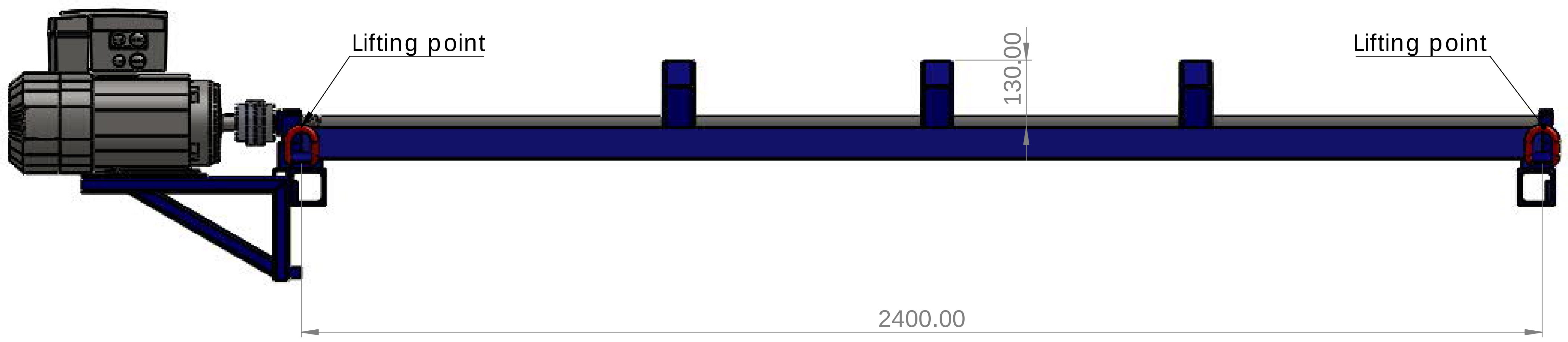
Side view



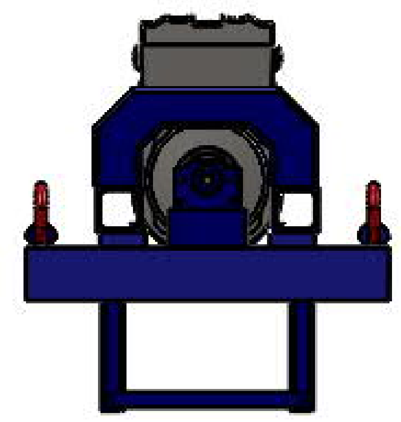
Top view



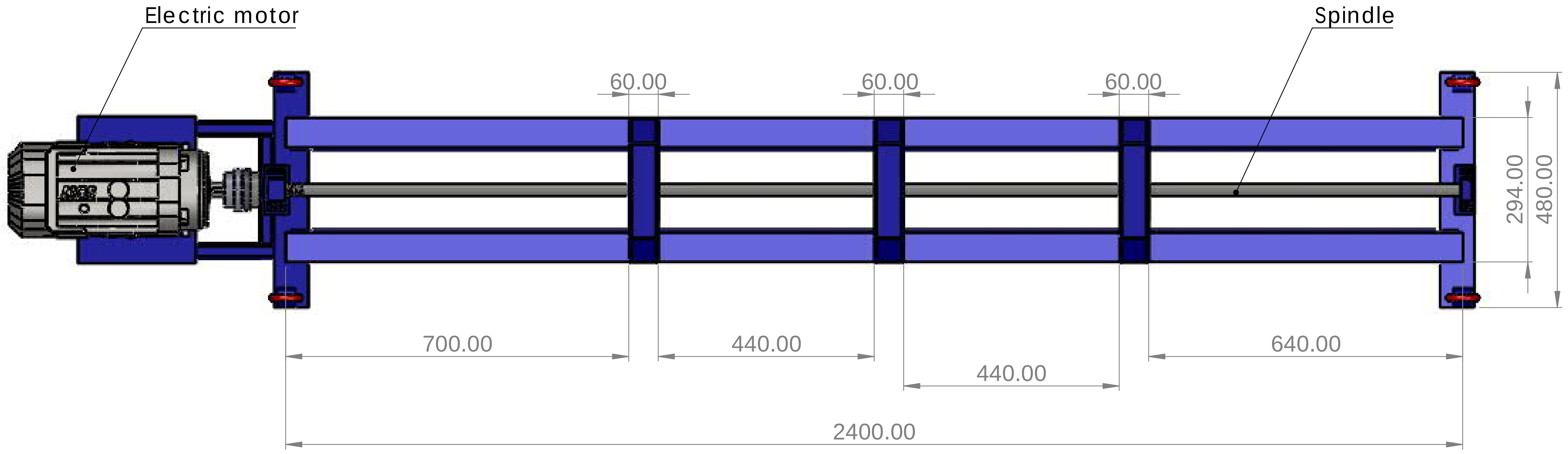
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	Mark Roos		01-05	Clay box	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Steel S355	DWG NO. 1.3	A3
			WEIGHT:	SCALE:1:10	SHEET 1 OF 1



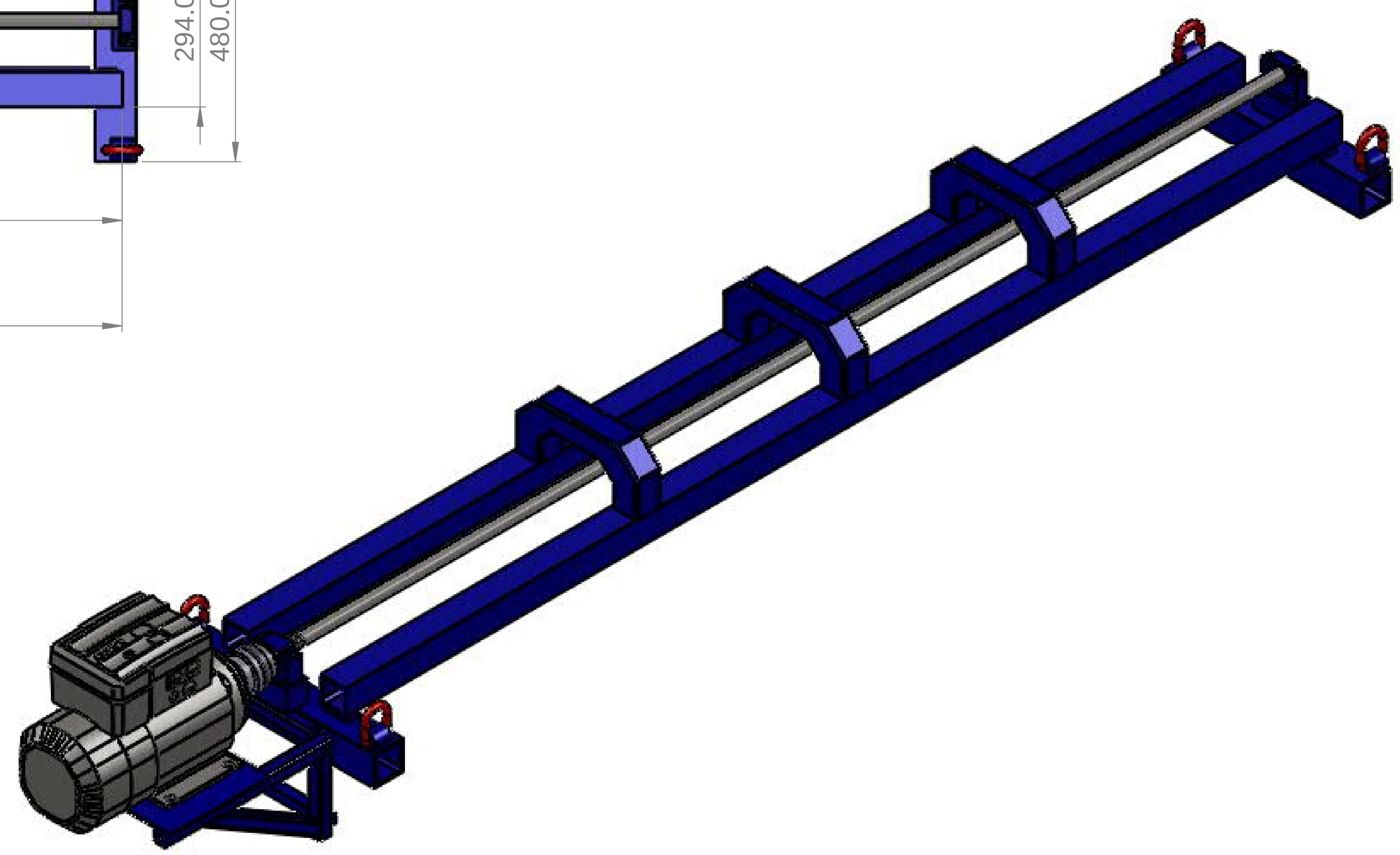
Right sideview



Front view



Top view



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Mark Roos		01-05
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

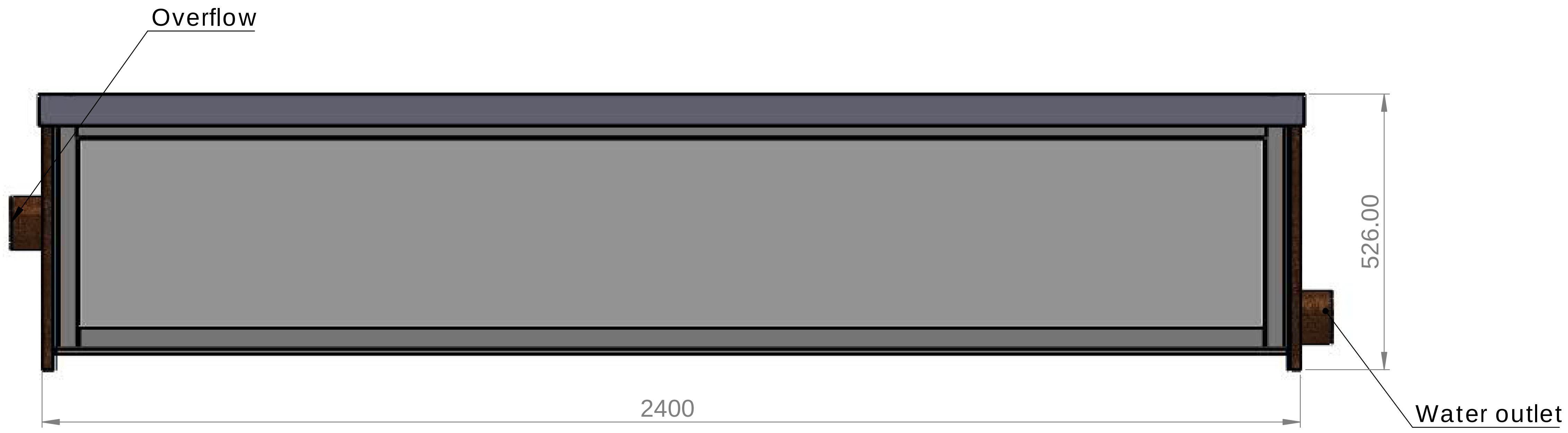
Guidance rail

DWG NO. 1.4

A2

SCALE:1:20

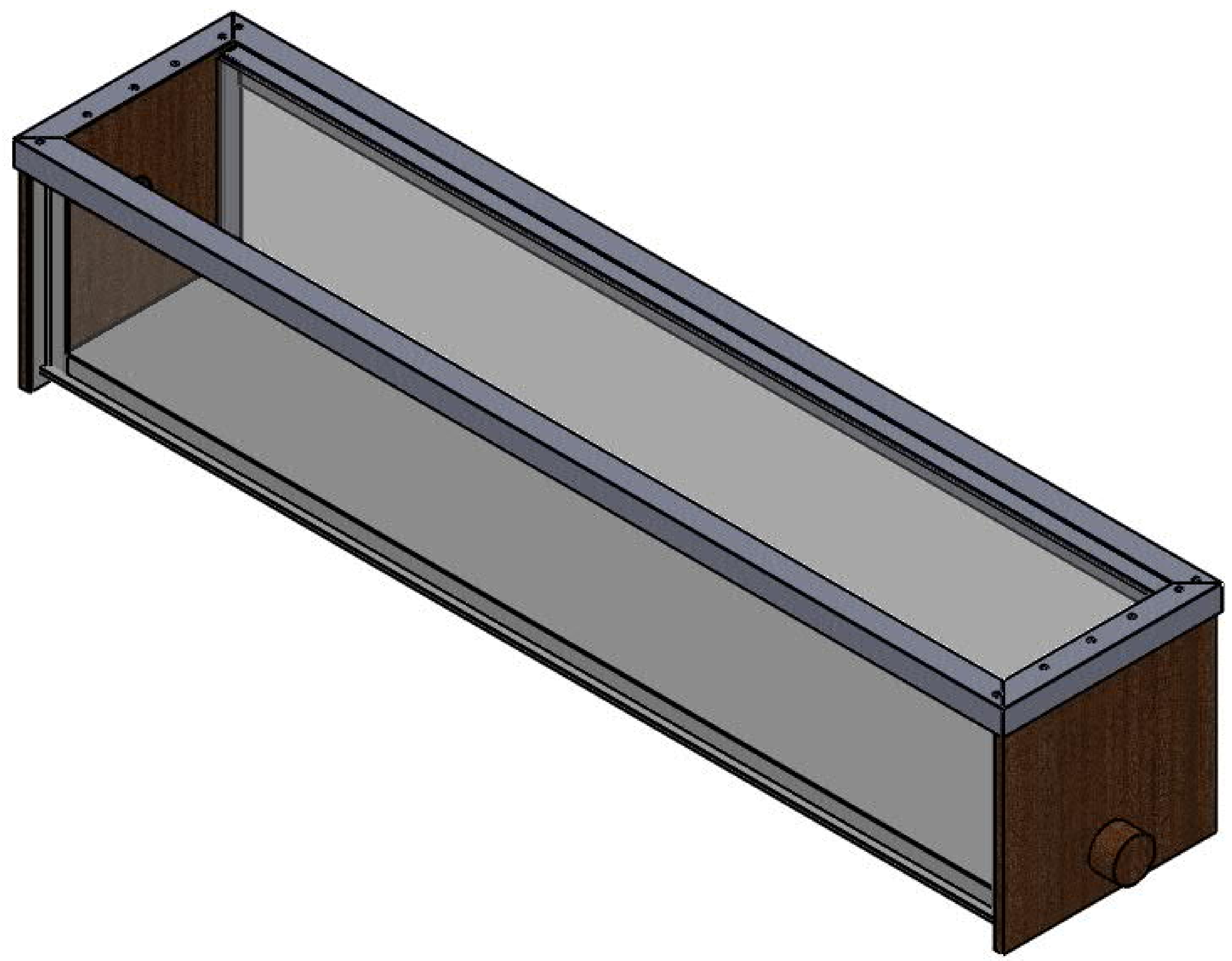
SHEET 1 OF 1



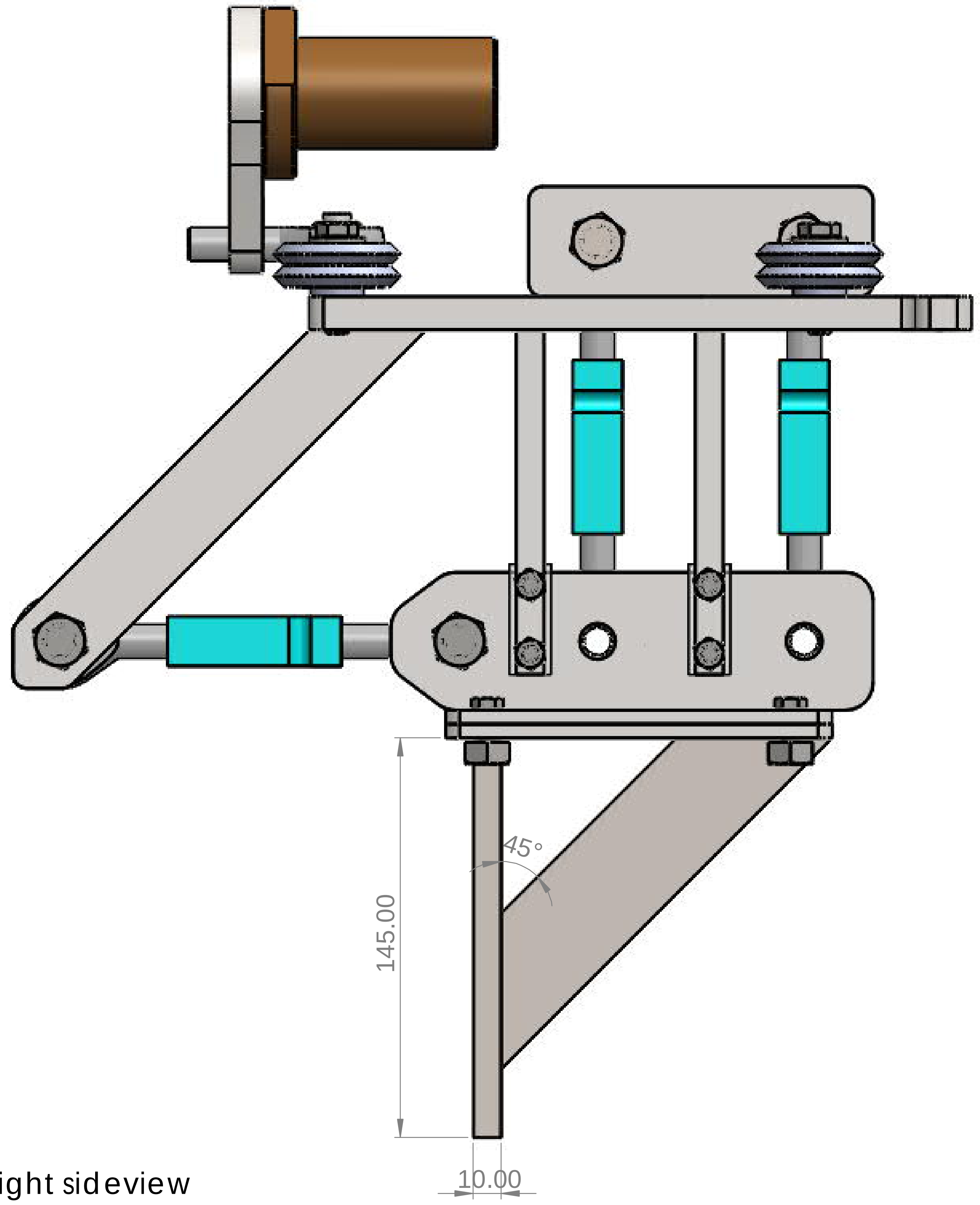
Front view

Right sideview

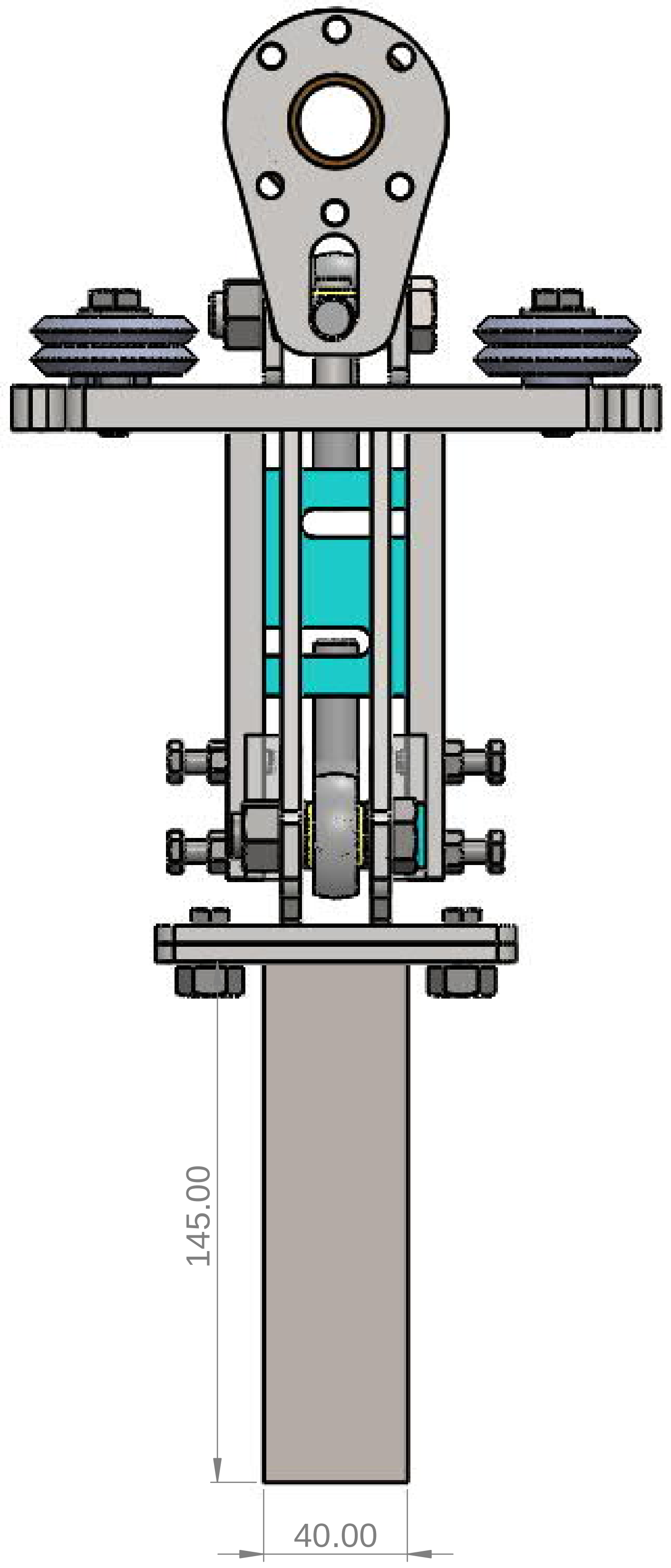
Top view



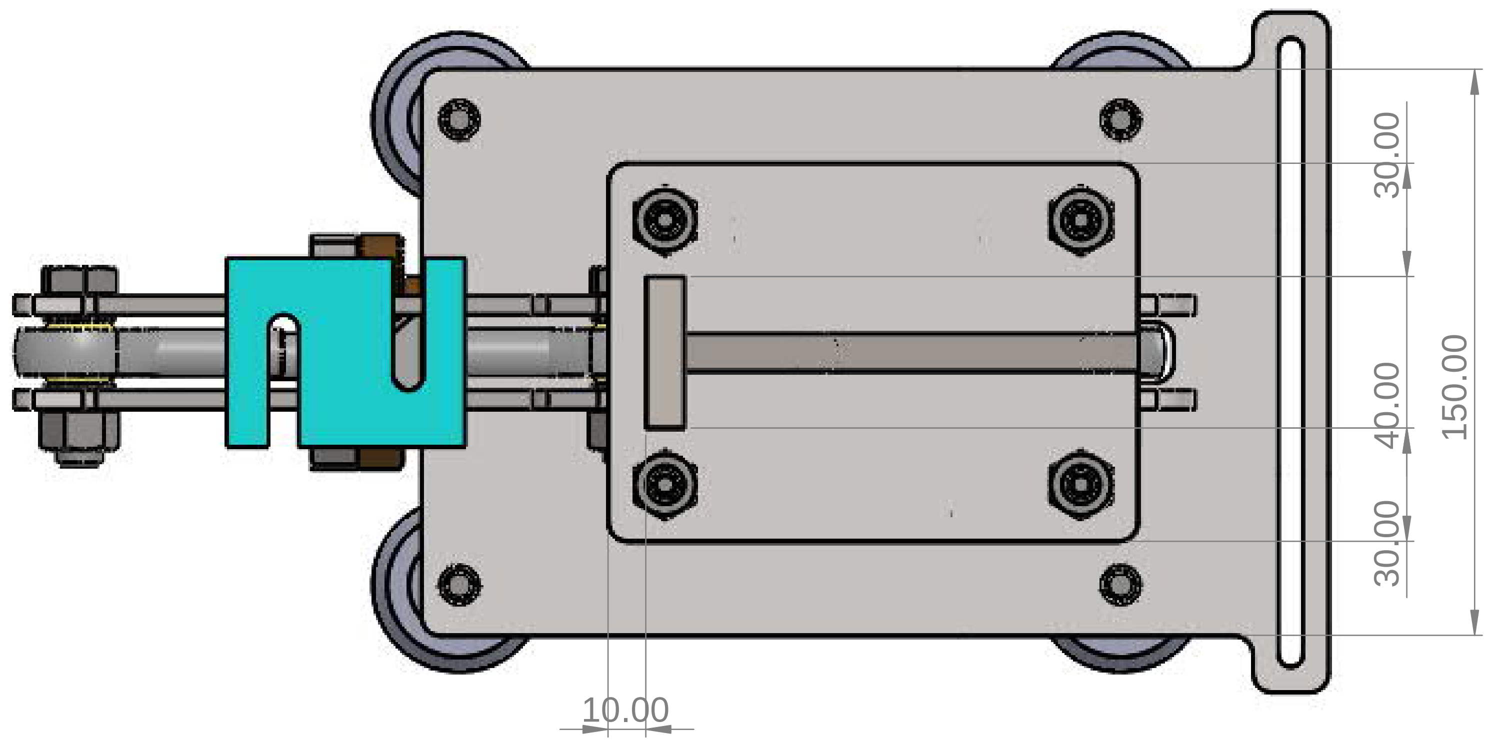
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE: Holding box	
DRAWN	Mark Roos		01-05			
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: Steel S355	DWG NO. 1.5	A2
				WEIGHT:	SCALE:1:10	SHEET 1 OF 1



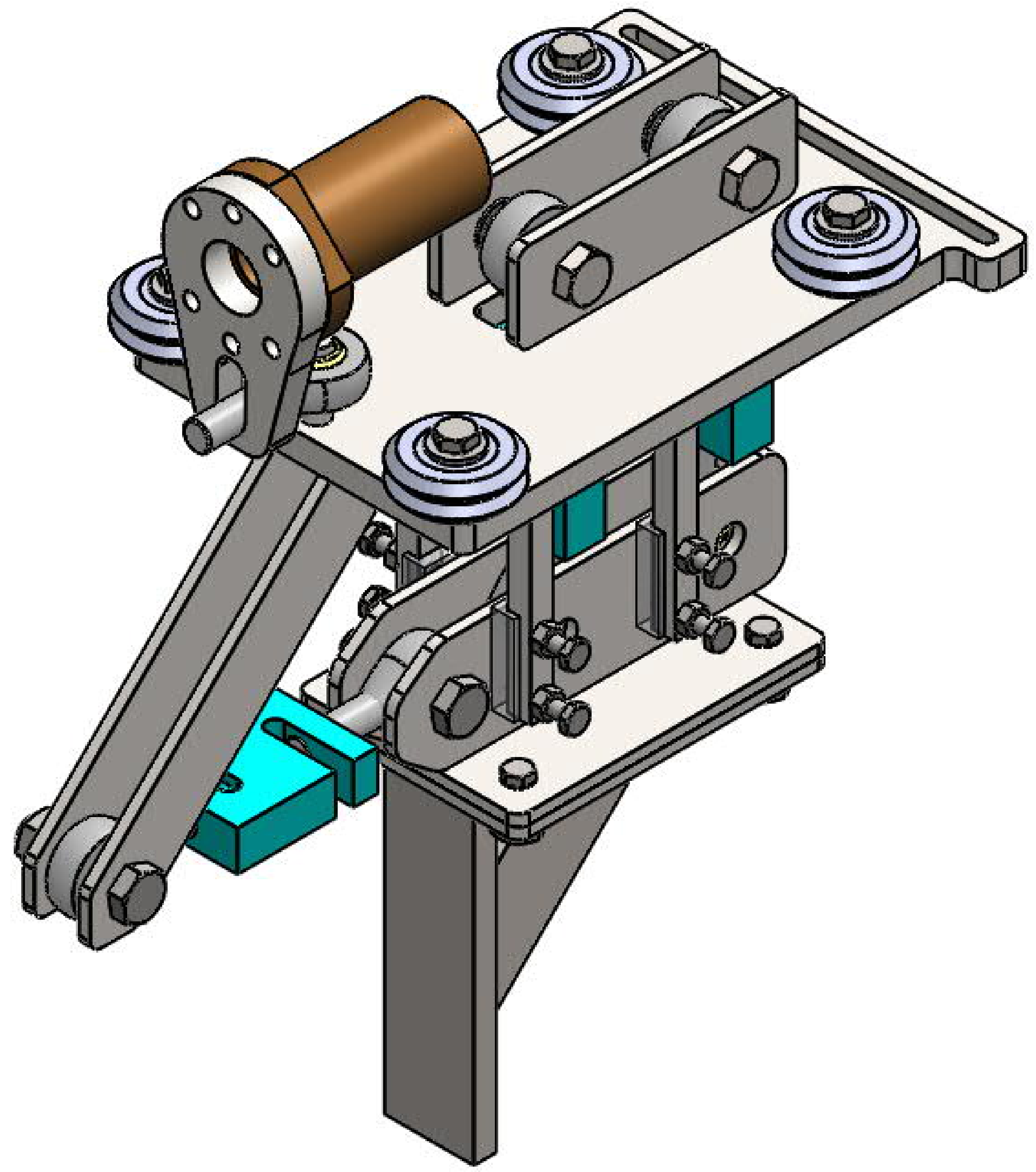
Right sideview



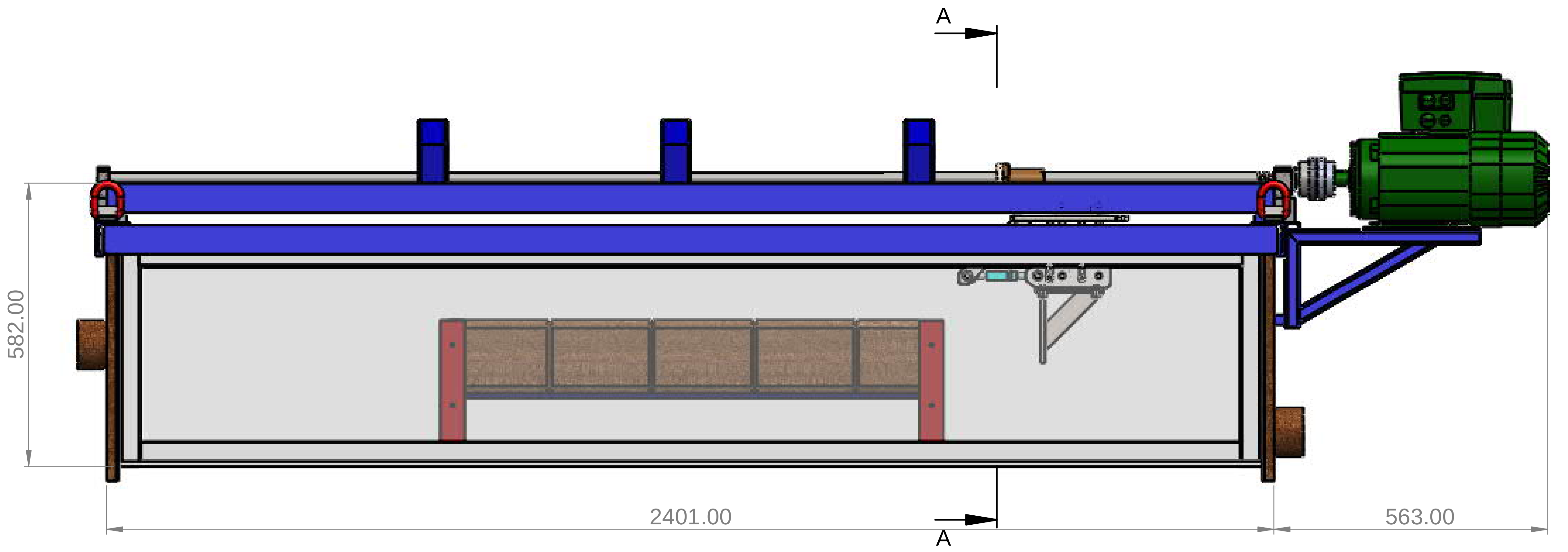
Front view



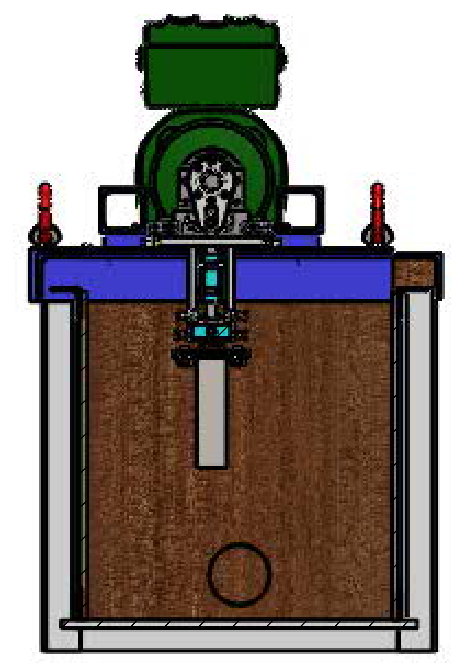
Bottom view



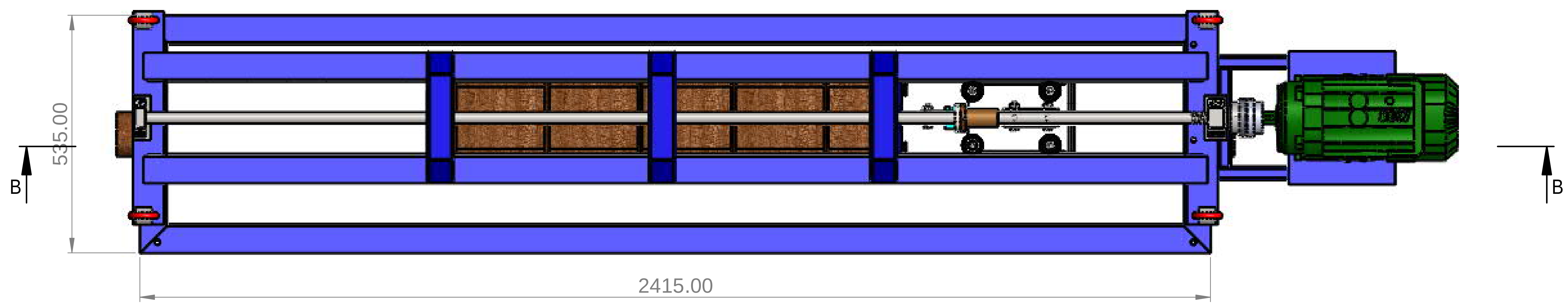
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE: Guidance cart	
DRAWN	Mark Roos		01-05			
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: Steel S355	DWG NO. 1.6	A2
				WEIGHT:	SCALE:1:5	SHEET 1 OF 1



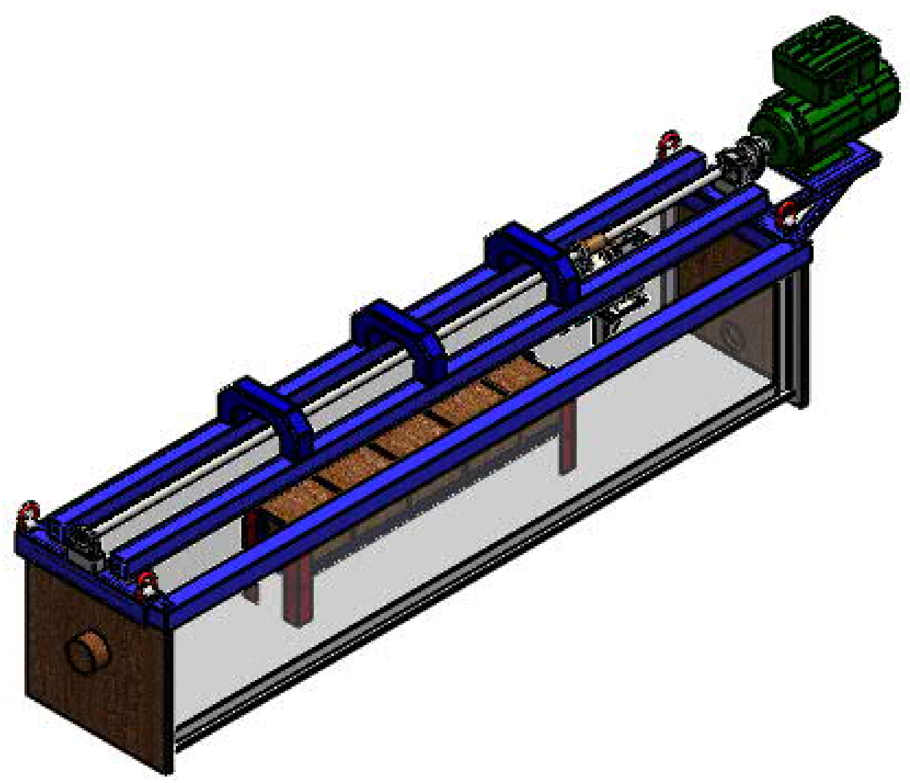
Front view

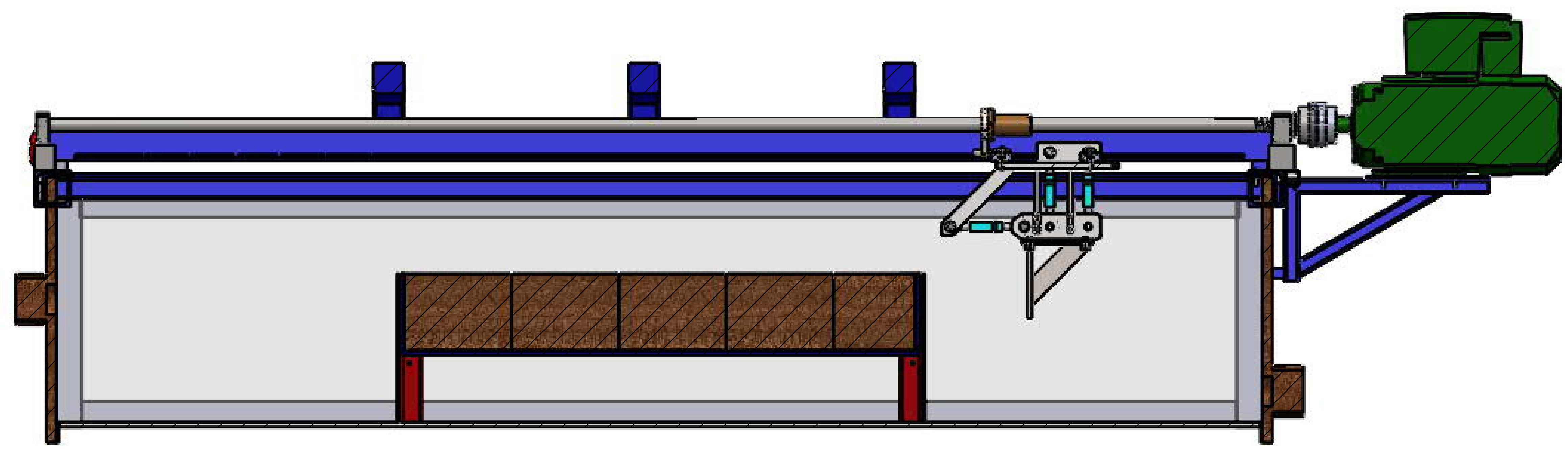


SECTION A-A



Top view





SECTION B-B

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE: Total assembly	
DRAWN	Mark Roos		01-05		
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL: Steel S355	DWG NO. 2.1 — A2
				WEIGHT:	SCALE:1:10/1:5 — SHEET 1 OF 1

APPENDIX D

Dolman lab results

Boskalis Environmental B.V.
Laboratory
Rosmolenweg 20
3356 LK Papendrecht
PO Box 76
3350 AB Papendrecht
The Netherlands

T +31 78 6969836
F +31 78 6969901

laboratorium@boskalis.com
www.boskalis.com/environmental

BBK BV - Central Business Support
attn. Mr. M. Roos
Rosmolenweg 20
3356 LK PAPENDRECHT

Subject

Trenching 1.5

Your reference

7530009

Our reference

233806

Page

1 of 3

Attachments

2

Dear Sir,

We are sending you the report regarding "Trenching 1.5, Boskalis afd. R&D".

Please do not hesitate to contact us if you have any questions concerning this report (+31 78 6969 836).

We trust to have informed you adequately.

Kind regards,

Jasper Visser

Royal Bank of Scotland N.V. Amsterdam
Account: 75.99.15.105
IBAN: NL86RBOS0759915105
BIC: RBOSNL2A

Vat No.
NL0048.22.833.B.01

Kamer van Koophandel
24.276.501

Boskalis Environmental

Project: Boskalis afd. R&D
Order: Trenching 1.5
Order number: 233806

Summary of results

Test	Unit	240120
Moisture content	%	27,9
Dry matter content	%	78,2
Density (Situ)	Mg/m^3	1,969
Specific gravity	Mg/m^3	2,601
Plastic limit	%	16
Liquid limit	%	45
Plasticity index	%	29
Density (Dry)	Mg/m^3	1,537

Nr.	Monsternaam
240120	01

Sampling:

The samples were delivered to us on 23 April 2019.

Sample storage:

Method/SOP information

TestType	Method	SOP-code
Density volume ring method (Dry)	NEN	W004
Density volume ring method (Situ)	NEN	W004
Particle size distribution (Hydrometer)	BS	W011
Liquid limit	RAW	W021
Moisture content	NEN-ISO	W002
Plastic limit	RAW	W021
Specific gravity	NEN	W006
Plasticity index	RAW	W021
Particle size distribution	BS	W010

Boskalis Environmental

Project	Trencing 1.5
Projectnumber	7530009
Order ID	233806
Lab technician	cehe

Sample name:	01	
V_{water}	43.2%	
V_{air}	-2.3%	
V_{solids}	59.1%	
Total volume in percentage	100%	

Remarks:
The above reported percentages are based on the raw data of the sample and tests. It can be assumed that almost no air is present in sample.

Boskalis Environmental

Project: Trenching 1.5 **Projectnummer:** 7530009 Methode: Gebaseerd op BS 1377
Labnummer: 233806

240120 - 01							
Maaswijdte zeef (µm)	Percentage door zeef	Maaswijdte zeef (µm)	Percentage door zeef	Maaswijdte zeef (µm)	Percentage door zeef	Maaswijdte zeef (µm)	Percentage door zeef
2000	100%						
1180	100%						
600	99%						
425	99%						
300	97%						
212	94%						
150	91%						
125	89%						
90	86%						
63	83%						
43	80%						
31	73%						
23	64%						
17	58%						
9	50%						
5	45%						
2	40%						
1	35%						

D90	137	D90		D90		D90	
D80	43	D80		D80		D80	
D70	28	D70		D70		D70	
D60	18	D60		D60		D60	
D50	9	D50		D50		D50	
D40	2	D40		D40		D40	
D30		D30		D30		D30	
D20		D20		D20		D20	
D10		D10		D10		D10	

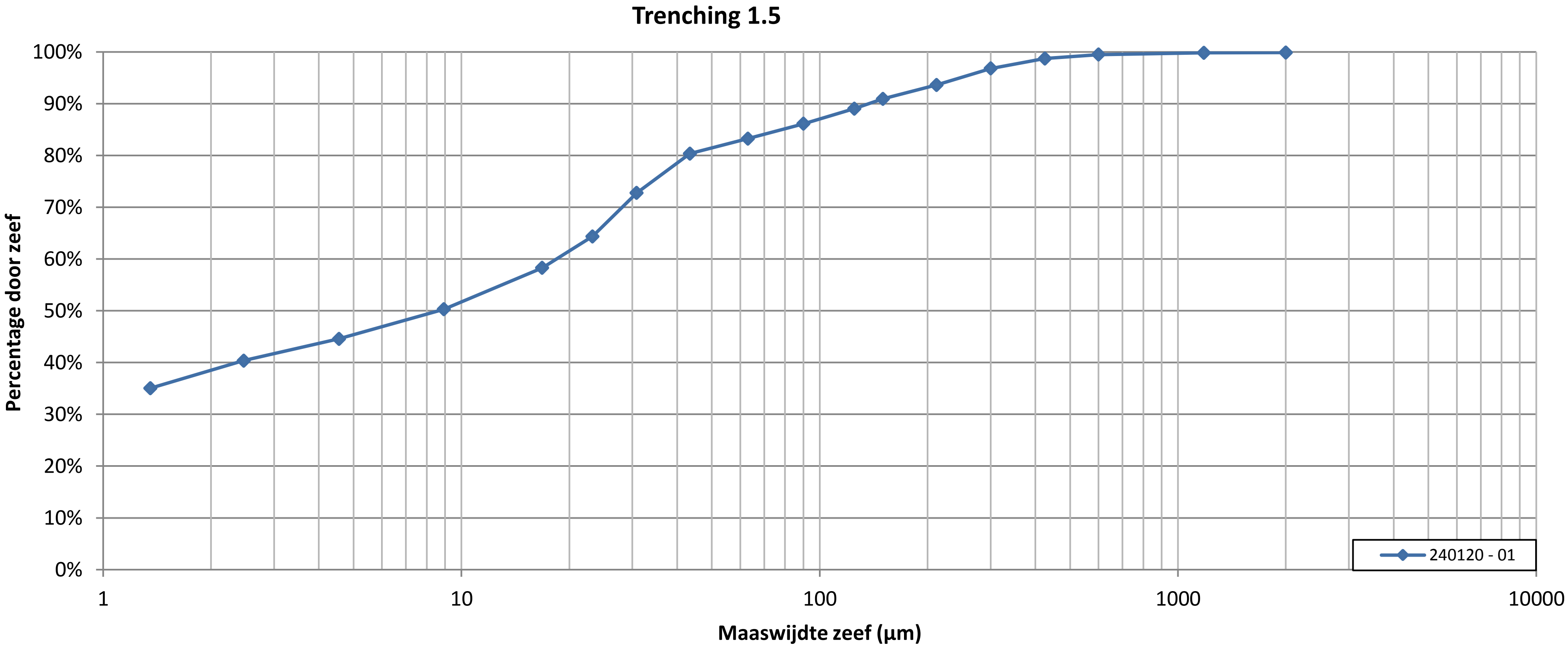
% > 2 mm	0%	% > 2 mm		% > 2 mm		% > 2 mm	
DMF totaal		DMF totaal		DMF totaal		DMF totaal	
D60/D10		D60/D10		D60/D10		D60/D10	

Opmerking:
De hierboven beschreven monsters zijn voorbehandeld waarbij de organische bestandsdelen verwijderd zijn. De massapercentages zijn enkel gebaseerd op de minerale bestandsdelen.

Boskalis Environmental

Labnummer: 233806

Projectnummer: 7530009



Monster:		D10	D20	D30	D40	D50	D60	D70	D80	D90	% > 2mm	DMF	D60/D10
Nummer	Naam	µm	µm	µm	µm	µm	µm	µm	µm	µm		(totaal)	
1	240120 - 01				2	9	18	28	43	137	0.1%		

APPENDIX E

Test results

TEST REPORT 1

General information

Test number:	1
Date of test:	7-Jul-2019
Time of test:	16:55
Assistant during test:	Dhr. Kamminga

Test discription

This test is to set the boundary conditions for the practical research. The first test will be without a jet attached to the plough to see what the forces are that, are acting on the plough without the reduction caused by the jet

Test Parameters

Nozzle diameter:	0	[mm]
Nozzle distance:	0	[mm]
Stand of distance:	0	[mm]
Jet pressure:	0	[bar]
Flow	0	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	45	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

No remarks

Remarks during the test:

No remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	47,5	[kPa]
Average shear strength**:	46,7	[kPa]

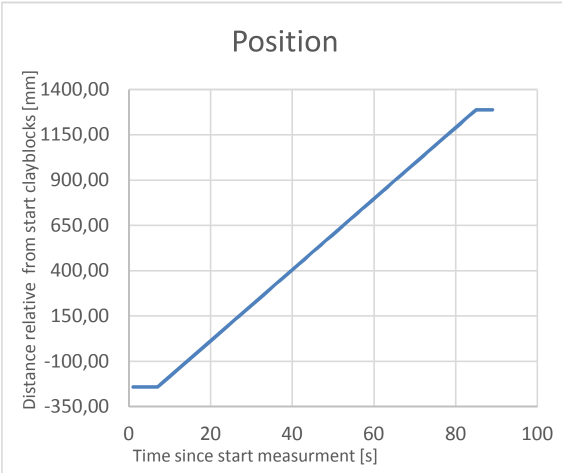
After ploughing		
Average shear strength*:	48,3	[kPa]
Average shear strength**:	40,0	[kPa]

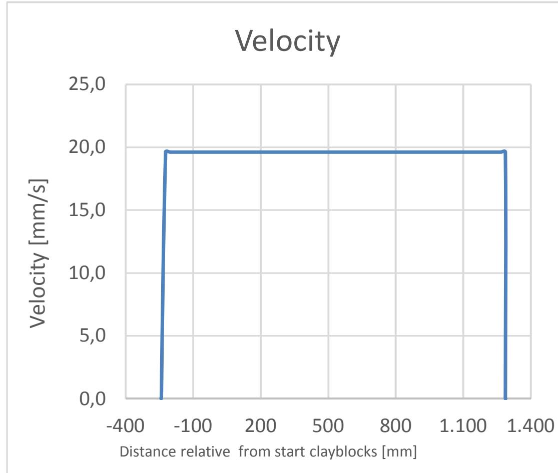
*field vane
**hand vane

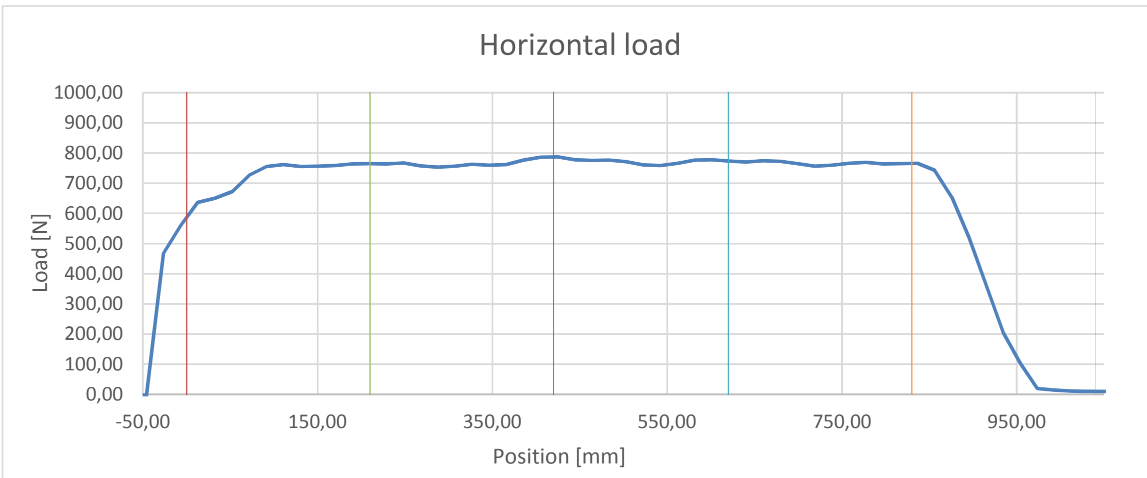
Averages in measuring length		
Start measuring length	-242,0	[mm]
End measurement length	1150,2	[mm]
Total length	1392,2	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	764,8	[N]
Total Vertical load	104,5	[N]
Total force	771,9	[N]
Angle of total force	7,8	[Degree]

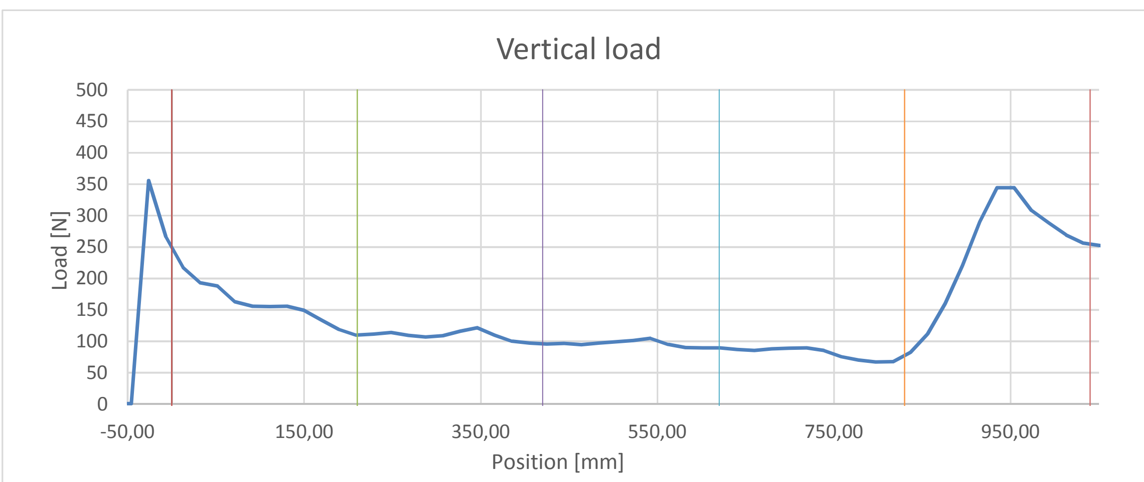
Plough model

Measured results









Clay block before ploughing

Top view after ploughing

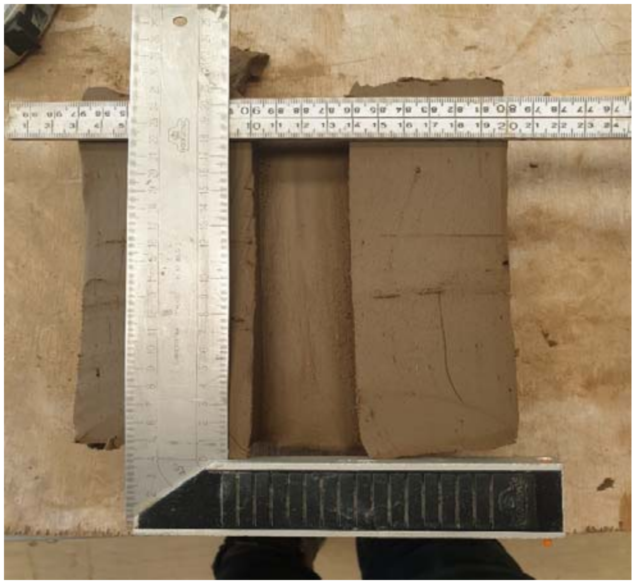
Side view plough after trenching

Front view plough after trenching

Front view after ploughing

Intersection in width of the clay block after ploughing

intersection in length of the clay block after ploughing



TEST REPORT 2

General information

Test number:	2
Date of test:	9-Jul-2019
Time of test:	13:58
Assistant during test:	Dhr. Nobel

Test discription

Test two will be the first test with the nozzle attached. This test will be conducted with a plough nozzle distance of 45mm and a nozzle diameter of 5mm

Focus is to check the forces on the plough within the effective area of the plough

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	45	[mm]
Stand of distance:	10	[mm]
Jet pressure:	32	[bar]
Flow	5,09	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	60	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

due to a to large spacing between the wooden strips where the clay on rested. The expectation of this larger spacing was that the clay would break out on the bottom and influencing the results. In consultation with Dhr. Nobel test three wil be the same as test and see if the results are simular

Remarks during the test:

Before the plough went in the clay it came in touch with the steel headplate of the clayholder, this is the reason there was a large spike in the scheme

Material properties of the clay

Before ploughing		
Average shear strength*:	52,5	[kPa]
Average shear strength**:	49,3	[kPa]

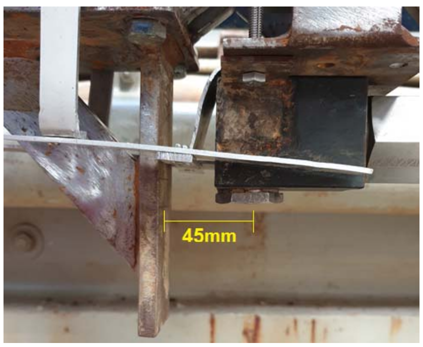
After ploughing		
Average shear strength*:	50,7	[kPa]
Average shear strength**:	42,0	[kPa]

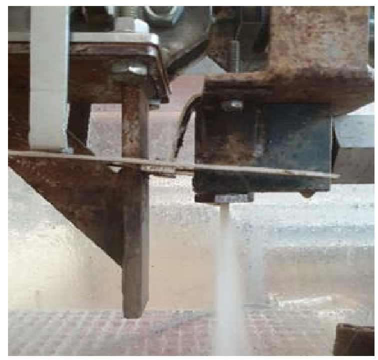
*field vane
**hand vane

Averages in measuring length

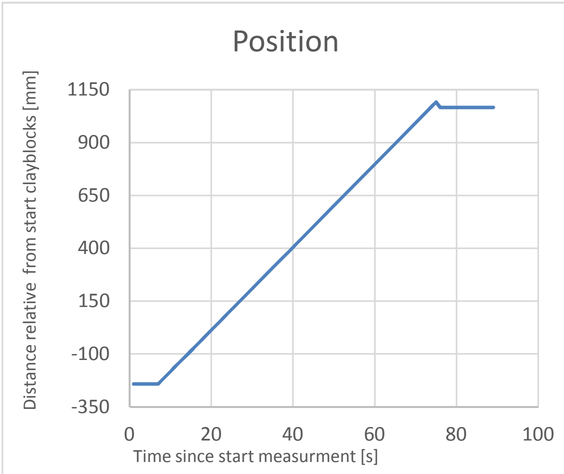
Start measuring length	-242,0	[mm]
End measurement length	1150,2	[mm]
Total length	1392,2	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	340,5	[N]
Total Vertical load	222,2	[N]
Total force	406,6	[N]
Angle of total force	33,1	[Degree]

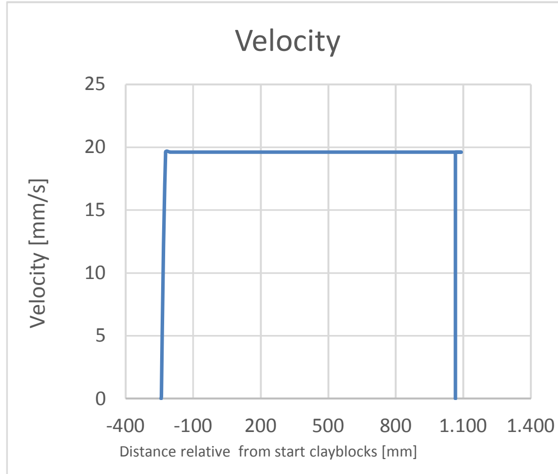
Plough model

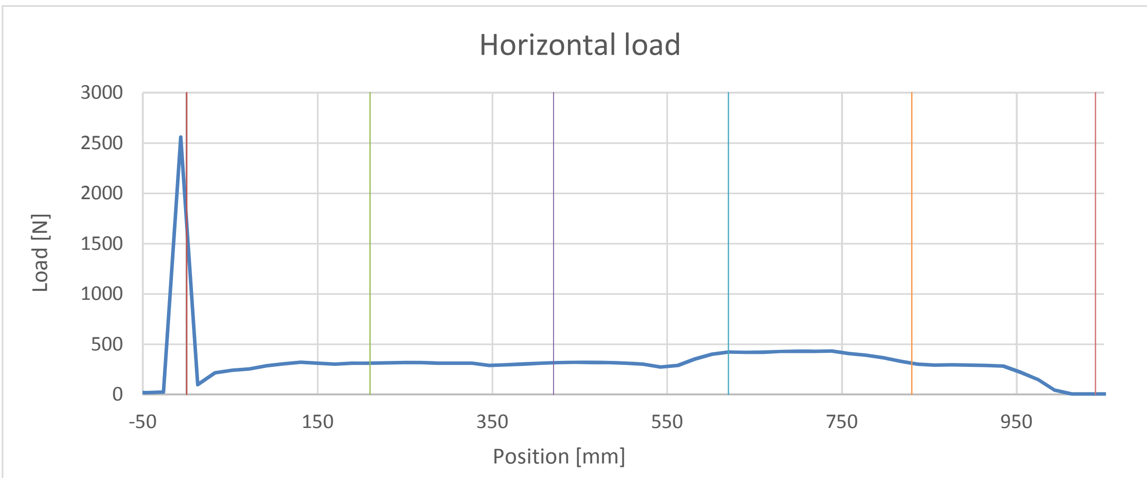


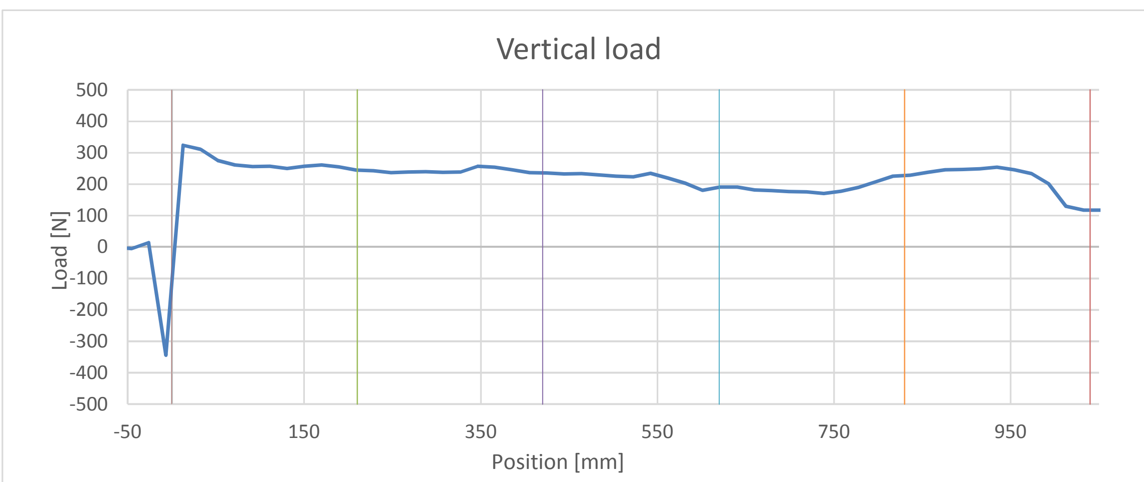


Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Front view after trenching

Width trench from ploughing

Cavity width created by the nozzle

intersection in length of the clay block after ploughing

TEST REPORT 3

General information

Test number:	3
Date of test:	10-Jul-2019
Time of test:	11:13
Assistant during test:	Dhr. Kamminga

Test discription

Test three will be conducted using the 5mm nozzle which is the smallest nozzle available, the plough-nozzle distance is 45mm and the stand of distance of the nozzle is 10mm.

The results from this test will be compaired to the boundary conditions to see what the reduction factor in forces is with the attachment of a nozzle which cuts through the entire block of clay

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	45	[mm]
Stand of distance:	10	[mm]
Jet pressure:	32	[bar]
Flow	5,09	[m3/h]
Plough velocity	20,00	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	65	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

No remarks

Remarks during the test:

No remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	50,0	[kPa]
Average shear strength**:	49,0	[kPa]

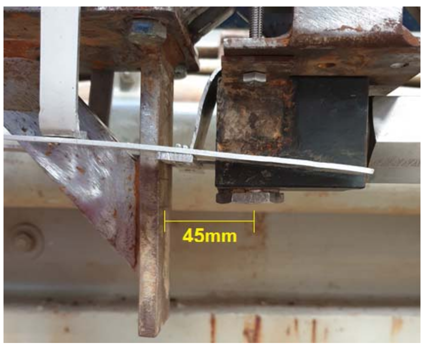
After ploughing		
Average shear strength*:	50,0	[kPa]
Average shear strength**:	42,0	[kPa]

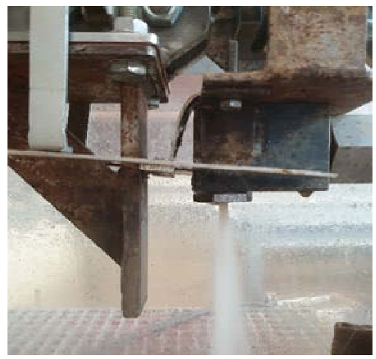
*field vane
**hand vane

Averages in measuring length		

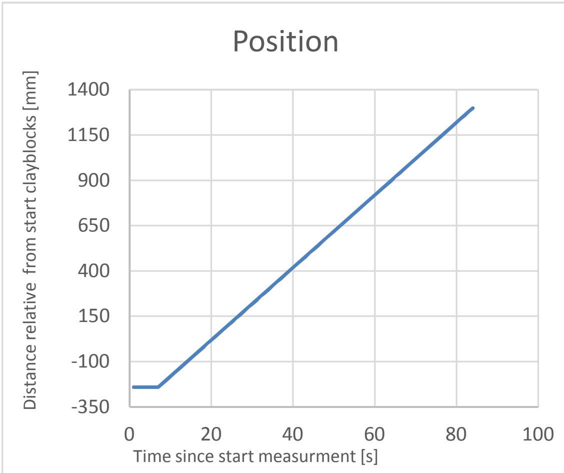
Start measuring length	-242,0	[mm]
End measurement length	1178,0	[mm]
Total length	1420,0	[mm]
Average speed	20	[mm/s]
Average speed	72,0	[m/hr]
Horizontal load cell	342,7	[N]
Total Vertical load	183,0	[N]
Total force	388,5	[N]
Angle of total force	28,1	[Degree]

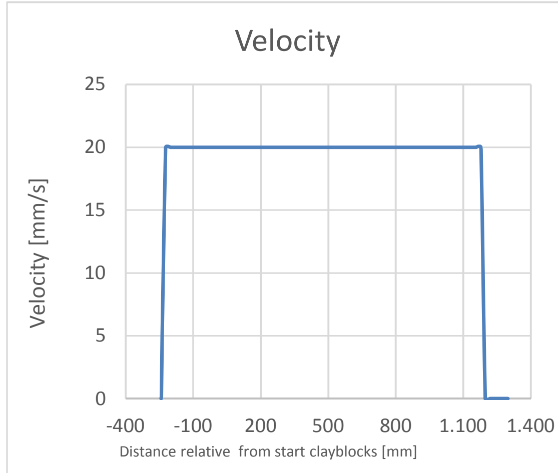
Plough model

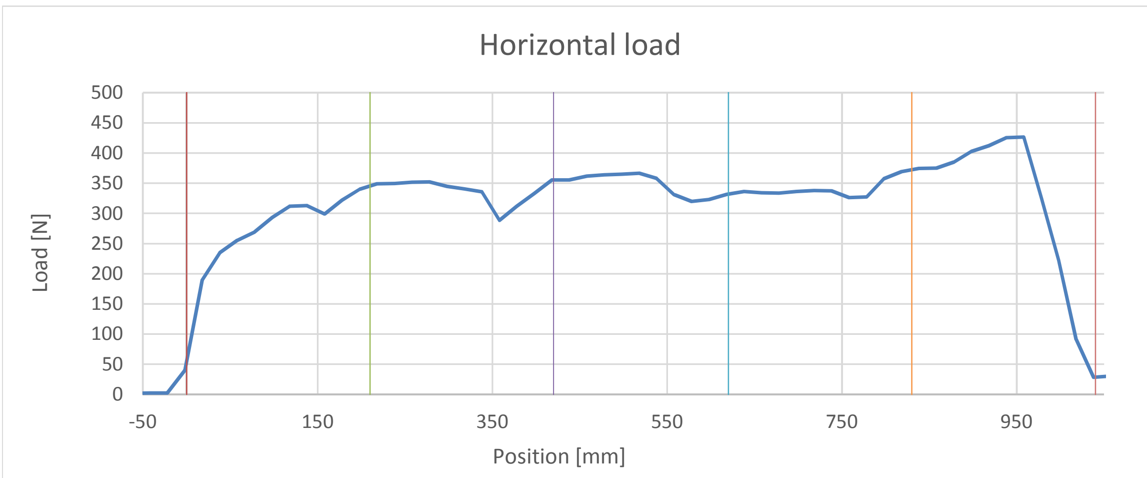


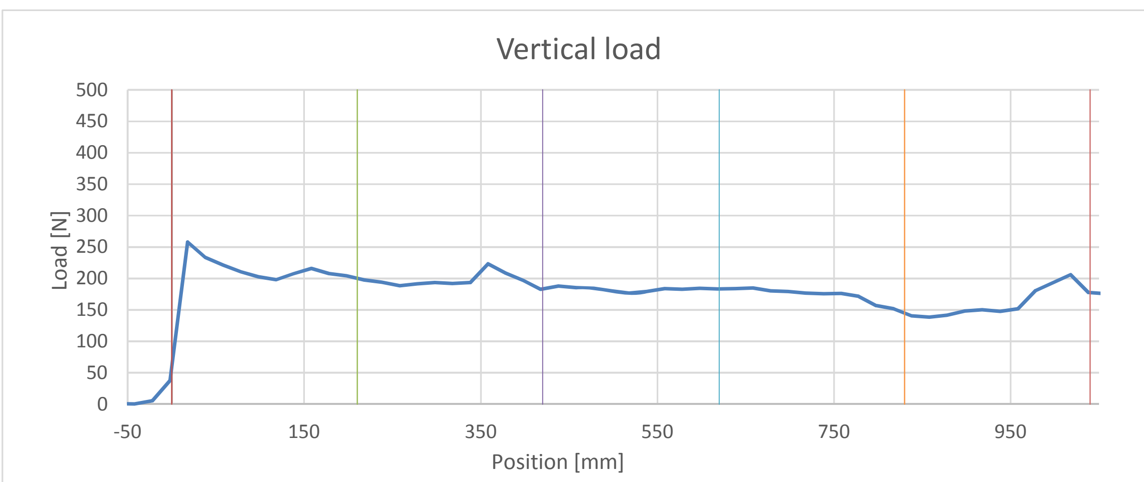


Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Front view after ploughing

Trench width of the plough

Cavity width created by the jetting nozzle

cross-section of the clay block after ploughing

TEST REPORT 4

General information

Test number:	4
Date of test:	12-Jul-2019
Time of test:	10:50
Assistant during test:	Dhr. Kamminga

Test discription

Test four will be conducted with the 5mm nozzle and a plough-nozzle distance of 75mm

To see what the change in forces is with a nozzle and without a nozzle the decision was made to turn the nozzle half way of and see if the forces of the plough alone will be the same as an entire test without a nozzle

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	75	[mm]
Stand of distance:	10	[mm]
Jet pressure:	31	[bar]
Flow	4,9	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	65	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

When checking the results, a malfunction of the sensor was found, during the entire test there was an additional 70 kilo on the plough, this made the results not trustworthy and the test will be re-done during test 5

Remarks during the test:

Before the plough went in the clay it came in touch with the steel headplate of the clayholder. To make sure this will not happen in any future tests the gap of the headplate was enlarged by 10mm.

Material properties of the clay

Before ploughing		
Average shear strength*:	49,0	[kPa]
Average shear strength**:	48,0	[kPa]

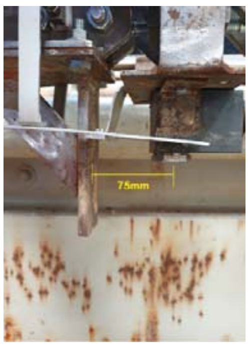
After ploughing		
Average shear strength*:	47,7	[kPa]
Average shear strength**:	37,3	[kPa]

*field vane
**hand vane

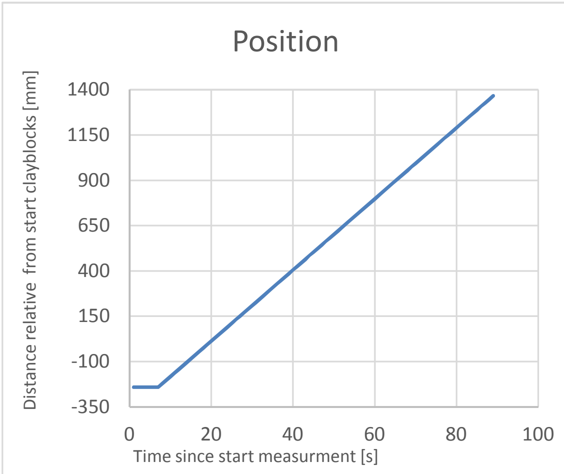
Averages in measuring length

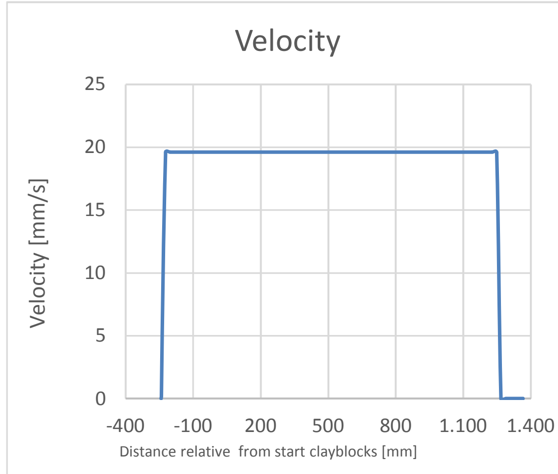
Start measuring length	-242,0	[mm]
End measurement length	1150,2	[mm]
Total length	1392,2	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	1058,4	[N]
Total Vertical load	-147,0	[N]
Total force	1068,6	[N]
Angle of total force	-7,9	[Degree]

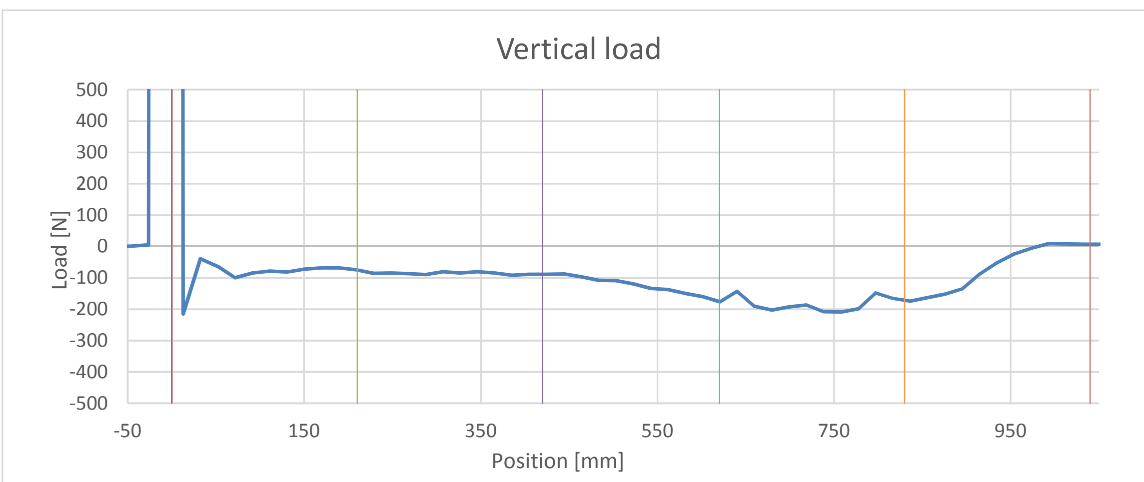
Plough model



Measured results







Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Front view after ploughing

Trench width of the plough

Cavity width created by the jetting nozzle

cross-section of the clay block after ploughing

TEST REPORT 5

General information

Test number:	5
Date of test:	12-Jul-2019
Time of test:	14:18
Assistant during test:	Dhr. Kamminga

Test discription

Test five will be conducted with the 5mm nozzle and a plough-nozzle distance of 75mm. This test will be the same as test four to see if the sensor that gave a wrong offset was stil good or not.

To see what the change in forces is with a nozzle and without a nozzle the decision was made to turn the nozzle half way through the experiment off and see if the forces of the plough alone will be the same as an test 1.

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	75	[mm]
Stand of distance:	10	[mm]
Jet pressure:	32	[bar]
Flow	5,09	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	60	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

Due to a malfunction sensor the first 250mm was not registrated, in consultation with Dhr. Nobel and Kamminga the sensor was replaced by a new one

Remarks during the test:

No remarks

Material properties of the clay

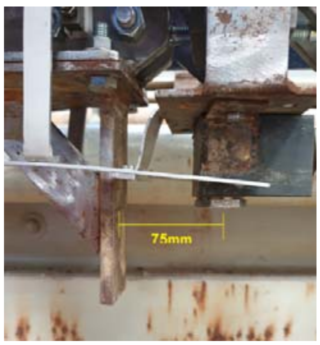
Before ploughing		
Average shear strength*:	49,5	[kPa]
Average shear strength**:	47,3	[kPa]

After ploughing		
Average shear strength*:	43,3	[kPa]
Average shear strength**:	44,7	[kPa]

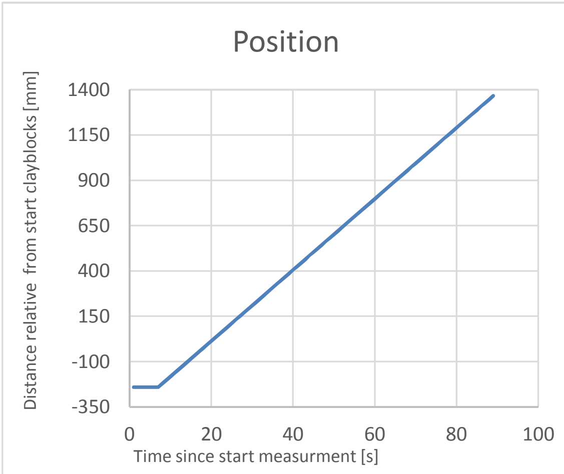
*field vane
**hand vane

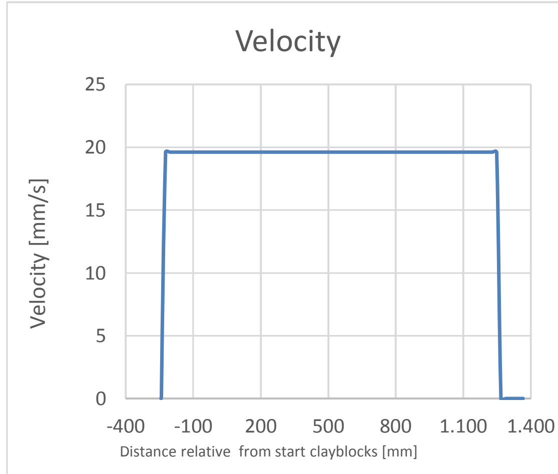
Averages in measuring length		
Start measuring length	-242,0	[mm]
End measurement length	1150,2	[mm]
Total length	1392,2	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	208,1	[N]
Total Vertical load	92,4	[N]
Total force	227,7	[N]
Angle of total force	23,9	[Degree]

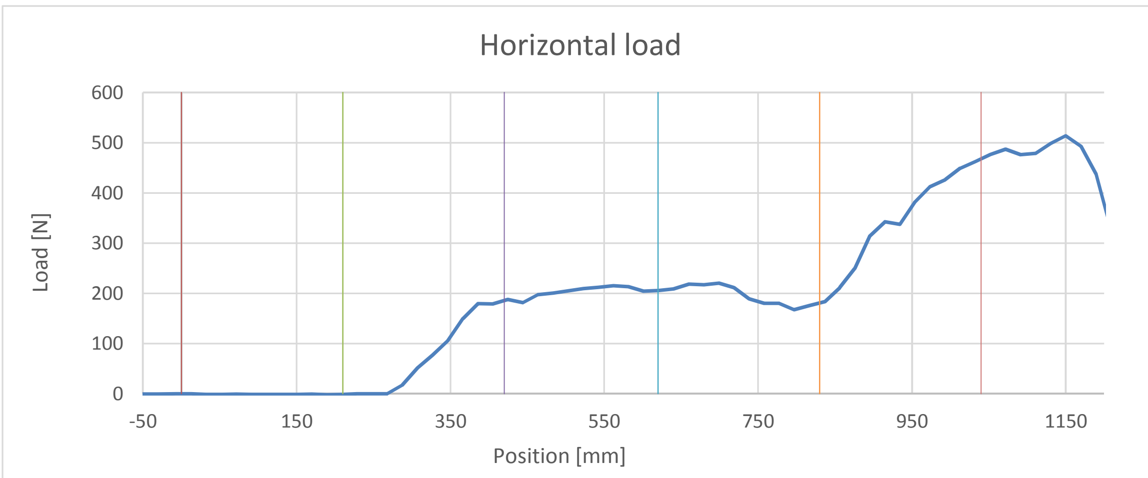
Plough model

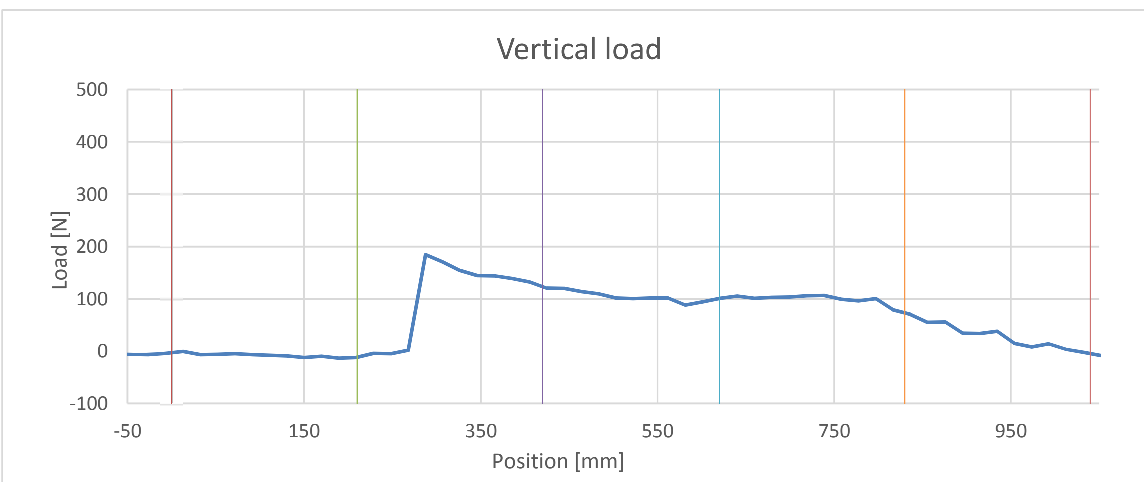


Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Front view after ploughing

Trench width of the plough

Cavity width created by the jetting nozzle

cross-section of the clay block after ploughing

The cavity created when the jet nozzle was turned off

TEST REPORT 6

General information

Test number:	6
Date of test:	16-Jul-2019
Time of test:	10:57
Assistant during test:	Dhr. Burgel

Test discription

Test 6 was a re-do of test one, the boundary conditions. The main focus of this test is to see if the results from test 1 are correct or aren't

Some changes had been made since the first test. The plough will not go through the entire clay block but will stop approx. 150-200mm before the end, because then additional measurements are taken in the influenced area with the hand vane

Test Parameters

Nozzle diameter:	0	[mm]
Nozzle distance:	0	[mm]
Stand of distance:	0	[mm]
Jet pressure:	0	[bar]
Flow	0	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	60	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

The plough won't go through the entire clay block so that it is possible to do additional measurements to see what the reach is of the influenced area of the plough

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	50,0	[kPa]
Average shear strength**:	45,7	[kPa]
Average remould strength**:	33,3	[kPa]

After ploughing		
Average shear strength*:	49,7	[kPa]
Average shear strength**:	42,3	[kPa]
Average remould strength**:	26,0	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	522,9	[N]
Total Vertical load	-2,3	[N]
Total force	522,9	[N]
Angle of total force	-0,3	[Degree]

Remoulding measurments

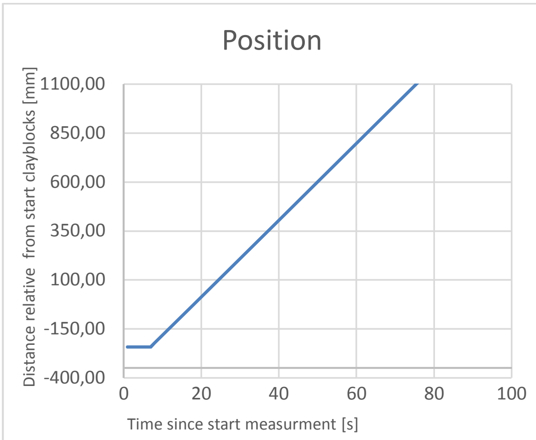
Location	Shear strength	remould	Unit
Left plough	30	27	[kPa]
Middle plough	38	24	[kPa]
Right plough	36	30	[kPa]
Plough +75mm	35	14	[kPa]
Plough + 110mm	40	30	[kPa]
Plough + 140mm	39	30	[kPa]
Average	36	26	[kPa]

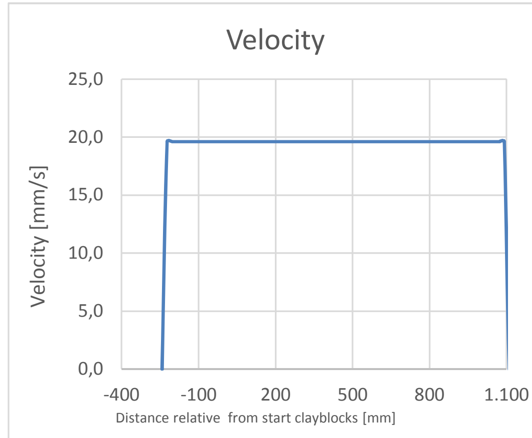
Remoulding conclusion

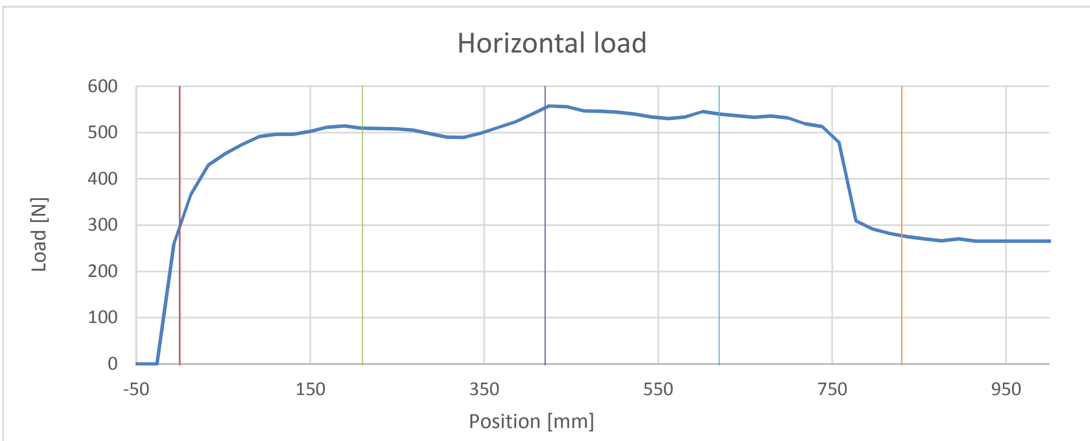
When the clay was cut to the height of the claybox the area of influence was clearly visuable due to the increase in height (indicated with the line), the area of influence was approx. 95mm in front of the plough

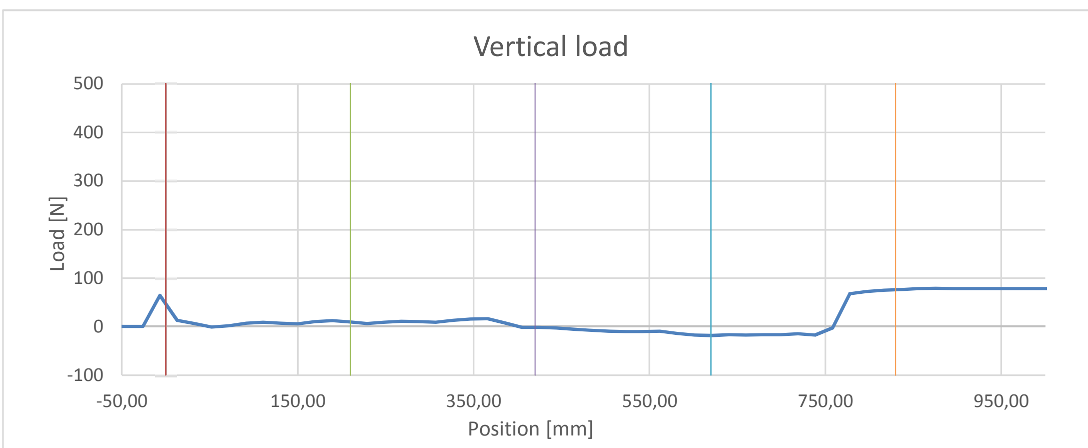
Ploughing model

Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

trench depth after ploughing

Trench width of the plough

area of incluence (indicated with line)

TEST REPORT 7

General information

Test number:	7
Date of test:	16-Jul-2019
Time of test:	15:27
Assistant during test:	Dhr. Burgel

Test discription

Test seven will be conducted with the 5mm nozzle and an plough-nozzle distance of 75mm

The main focus of this experiment is to see what the behavior is of the clay between the nozzle and the plough, will it fill up the hole created by the nozzle or not

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	75	[mm]
Stand of distance:	10	[mm]
Jet pressure:	32	[bar]
Flow:	5,09	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

no remarks

Remarks during the test:

The plough and jet was stopped at approx. 6550mm so that a good visual could be made of the behavior of the clay between the nozzle and the plough

Material properties of the clay

Before ploughing		
Average shear strength*:	53,0	[kPa]
Average shear strength**:	43,7	[kPa]

After ploughing		
Average shear strength*:	45,7	[kPa]
Average shear strength**:	39,7	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	1150,2	[mm]
Total length	1392,2	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	184,9	[N]
Total Vertical load	187,8	[N]
Total force	263,5	[N]
Angle of total force	45,4	[Degree]

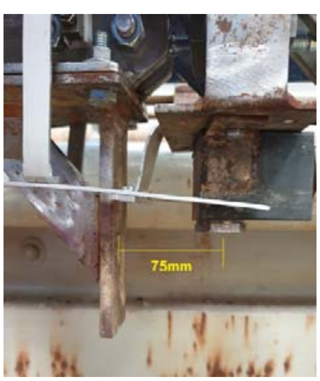
Remoulded measurements

Location	Shear strength	remould	Unit
Left plough	40	21	[kPa]
Middle plough	40	20	[kPa]
Right plough	30	18	[kPa]
Average	37	20	[kPa]

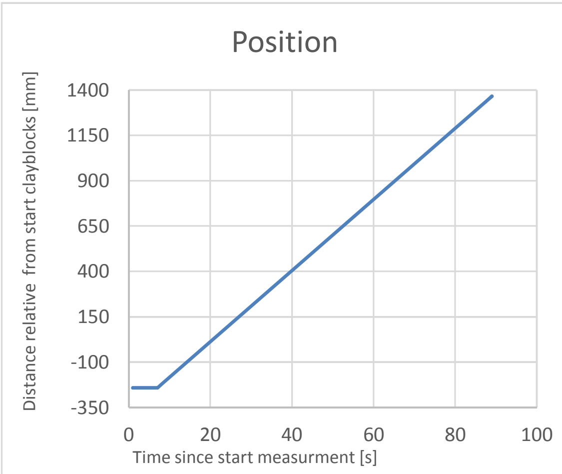
Remoulding conclusion

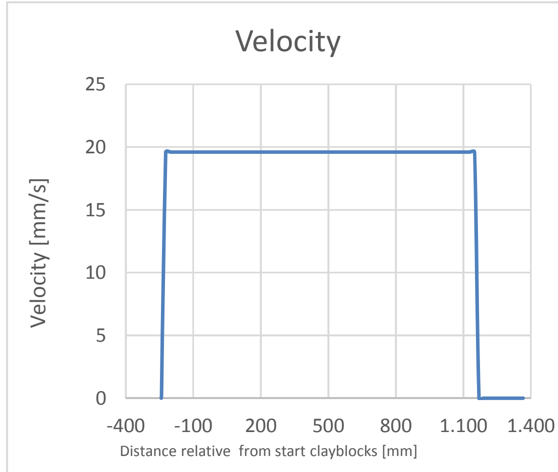
As expected the area inbetween the nozzle and the plough is filled back up by the plough, but the clay has a lower shear strength then the original clay.

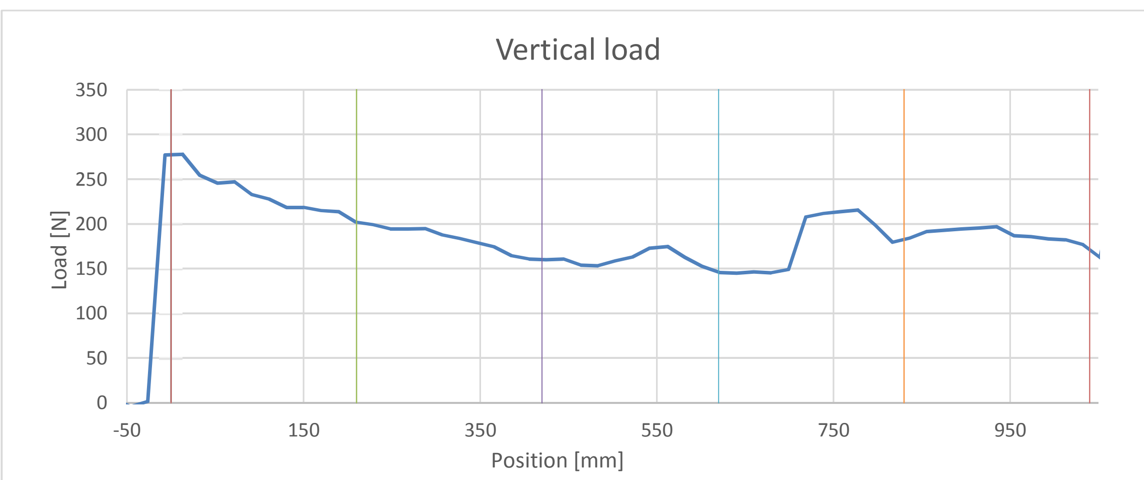
Ploughing model



Measured results







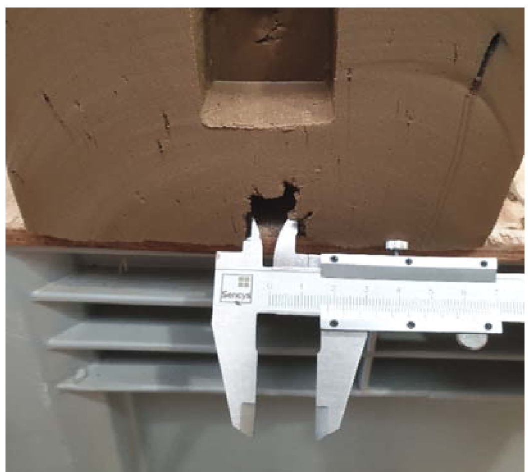
Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Trench width of the plough

Cavity width created by the jet nozzle



Width of the effective area from the plough

Length of the effective area infront of the plough

Bottom view of the cavity created by the nozzle

TEST REPORT 8

General information

Test number:	8
Date of test:	17-Jul-2019
Time of test:	11:12
Assistant during test:	Dhr. Boekraad

Test discription

Test eight will be conducted with the 5mm nozzle and an plough-nozzle distance of 105mm

The main focus of this experiement is to see if there are any differances between a nozzle that is outside the influenced area and one that is in the area

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	105	[mm]
Stand of distance:	10	[mm]
Jet pressure:	32	[bar]
Flow:	5,05	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

After seeing the results the area between 350mm and 630mm was not added into the results becaue the clay of that particular clayblock was 10 kPa higher then the others

Remarks during the test:

Tthe plough and nozzle was turned off at 750mm

Material properties of the clay

Before ploughing		
Average shear strength*:	59,0	[kPa]
Average shear strength**:	49,0	[kPa]
Average remould strength**:	29,3	[kPa]

After ploughing		
Average shear strength*:	51,7	[kPa]
Average shear strength**:	43,3	[kPa]
Average remould strength**:	23,3	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	954,1	[mm]
Total length	1196,1	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	264,1	[N]
Total Vertical load	202,4	[N]
Total force	332,8	[N]
Angle of total force	37,5	[Degree]

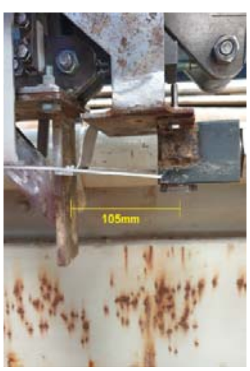
Remoulded measurements

Location	Shear strength	remould	Unit
Left plough	40	18	[kPa]
Middle plough	40	20	[kPa]
Right plough	35	22	[kPa]
Average	38	20	[kPa]

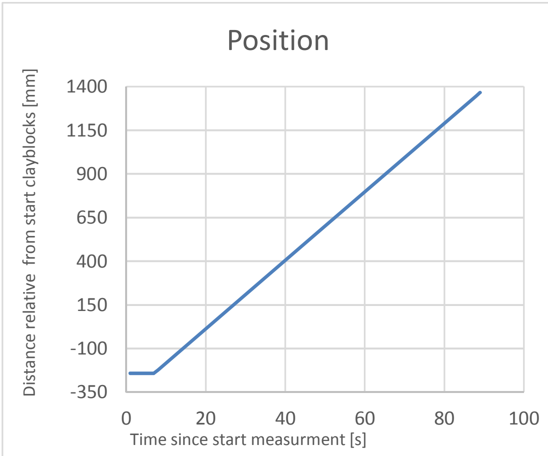
Remoulding conclusion

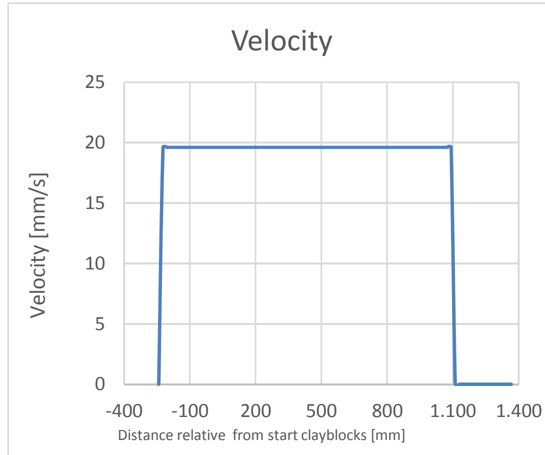
When the clay was cut to the height of the claybox the area of influence was clearly visuable due to the increase in height (indicated with the line), the area of influence was approx. 95mm in front of the plough

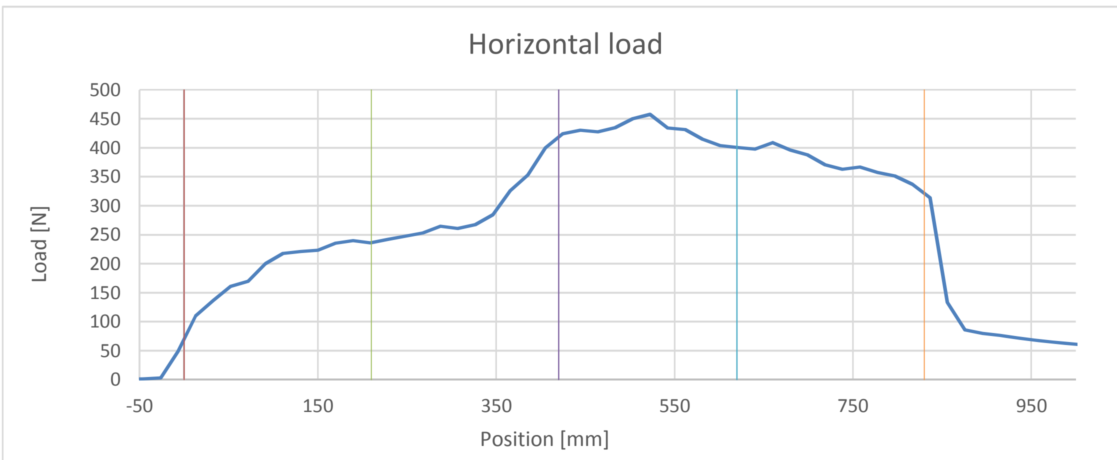
Plough model

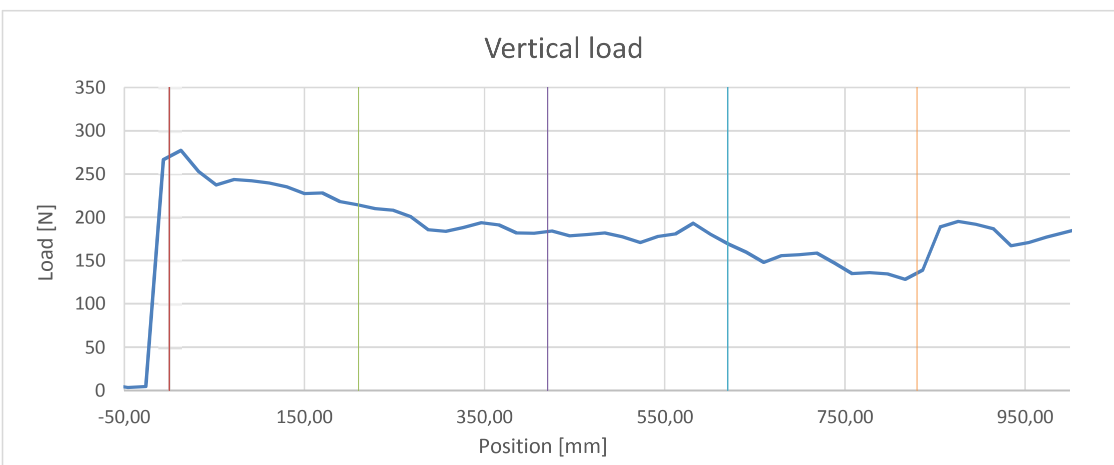


Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

trench depth after ploughing

Trench width of the plough

Cavity width of the nozzle

Area of incluence (indicated with line)

Bottom view of the cavity created by nozzle

TEST REPORT 9

General information

Test number:	9
Date of test:	17-Jul-2019
Time of test:	16:48
Assistant during test:	Dhr. Boekraad

Test discription

Test nine was conducted with a 10mm nozzle and 45mm plough - nozzle distance

The main objective of this test was to compair the results with the smaller nozzle to see if the larger nozzle has influence on the forces.

Test Parameters

Nozzle diameter:	10	[mm]
Nozzle distance:	45	[mm]
Stand of distance:	10	[mm]
Jet pressure:	21	[bar]
Flow:	15,8	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

Before starting we discovered a malfunction of the flow meter. Unfortunatly a mechanic came and try to repair it but was not able to repair it. Reason for the malfunction: water on the computer inside the flowmeter due to water sepage inside the sensor

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	55,0	[kPa]
Average shear strength**:	46,3	[kPa]
Average remould strength**:	23,3	[kPa]

After ploughing		
Average shear strength*:	48,0	[kPa]
Average shear strength**:	36,7	[kPa]
Average remould strength**:	15,0	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	159,3	[N]
Total Vertical load	177,2	[N]
Total force	238,3	[N]
Angle of total force	48,0	[Degree]

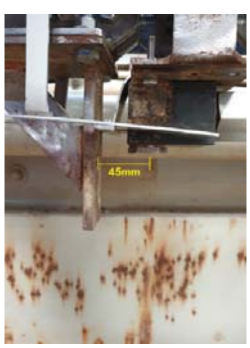
Remoulding measurements

Location	Shear strength	remould	Unit
Left plough	34	20	[kPa]
Middle plough	22	10	[kPa]
Right plough	32	20	[kPa]
Plough +75mm	30	12	[kPa]
Plough + 110mm	30	18	[kPa]
Average	30	16	[kPa]

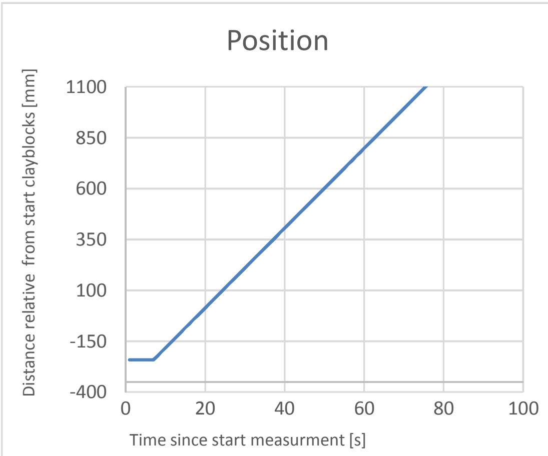
Remoulding conclusion

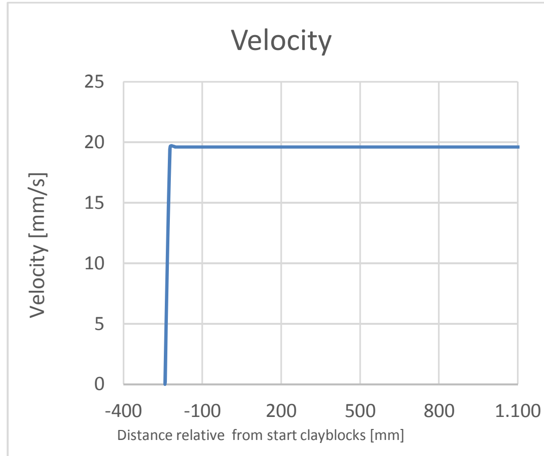
The influenced area between the two nozzle sizes got from 110mm to 80mm this as a results of a large nozzle

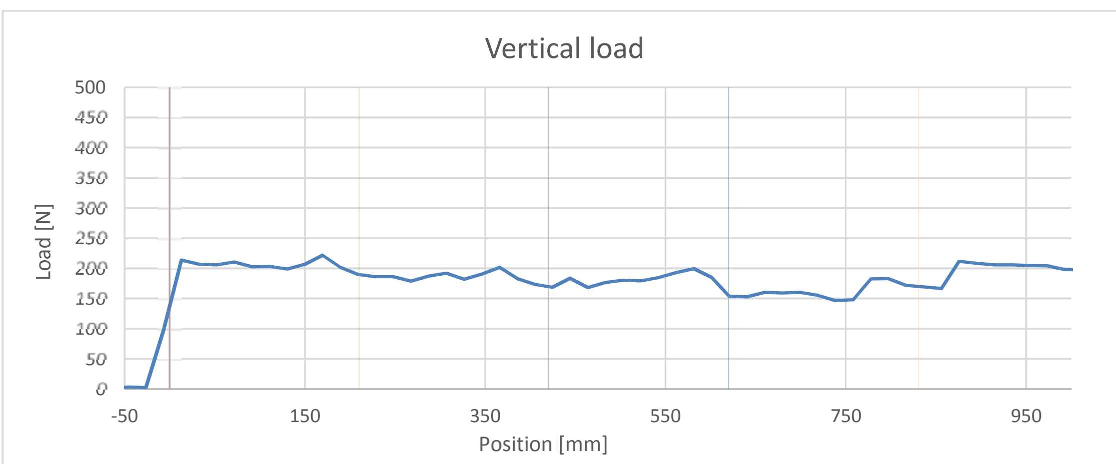
Remoulded measurements



Measured results







Clay block before ploughing

Top view after ploughing

Side view plough after trenching

trench depth after ploughing

Trench width of the plough

Cavity width of the nozzle

area of influence of the plough

Closing of the nozzle cavity due to ploughing

Bottom view of the created cavity

TEST REPORT 10

General information

Test number:	10
Date of test:	18-Jul-2019
Time of test:	12:19
Assistant during test:	Dhr. Kamminga

Test discription

Test nine was conducted with a 10mm nozzle and 105mm plough - nozzle distance

The main objective of this test was to compair the results with the smaller nozzle to see if the influenced area of the plough is the simular.

Test Parameters

Nozzle diameter:	10	[mm]
Nozzle distance:	105	[mm]
Stand of distance:	10	[mm]
Jet pressure:	21	[bar]
Flow:	15,8	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

No remarks

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	48,0	[kPa]
Average shear strength**:	41,7	[kPa]
Average remould strength**:	27,0	[kPa]

After ploughing		
Average shear strength*:	45,7	[kPa]
Average shear strength**:	37,7	[kPa]
Average remould strength**:	22,0	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	228,0	[N]
Total Vertical load	250,7	[N]
Total force	338,8	[N]
Angle of total force	47,7	[Degree]

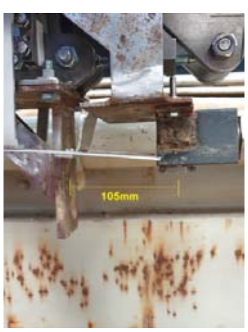
Remoulding measurements

Location	Shear strength	remould	Unit
Left plough	35	28	[kPa]
Middle plough	35	18	[kPa]
Right plough	25	17	[kPa]
Average	32	21	[kPa]

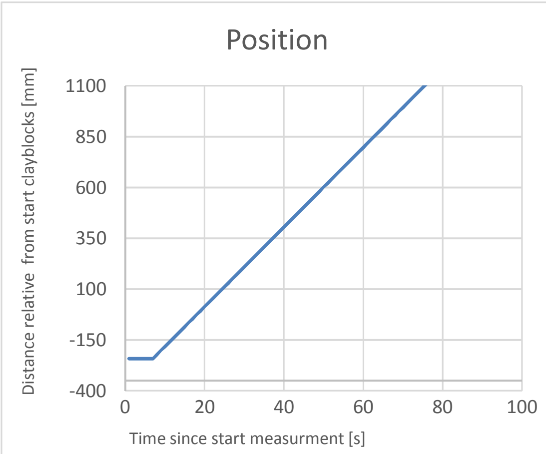
Remoulding conclusion

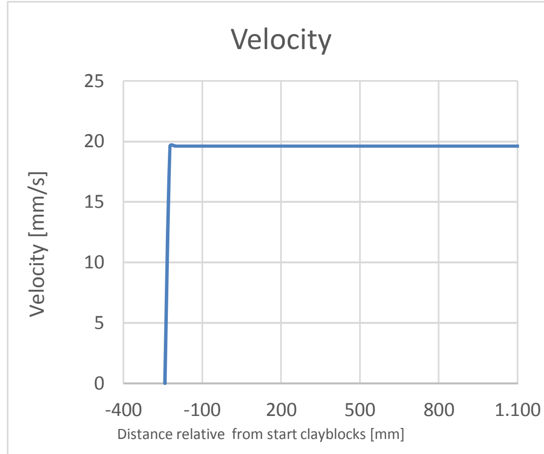
The influenced area between the two nozzle sizes got from 110mm to 80mm this as a results of a large nozzle

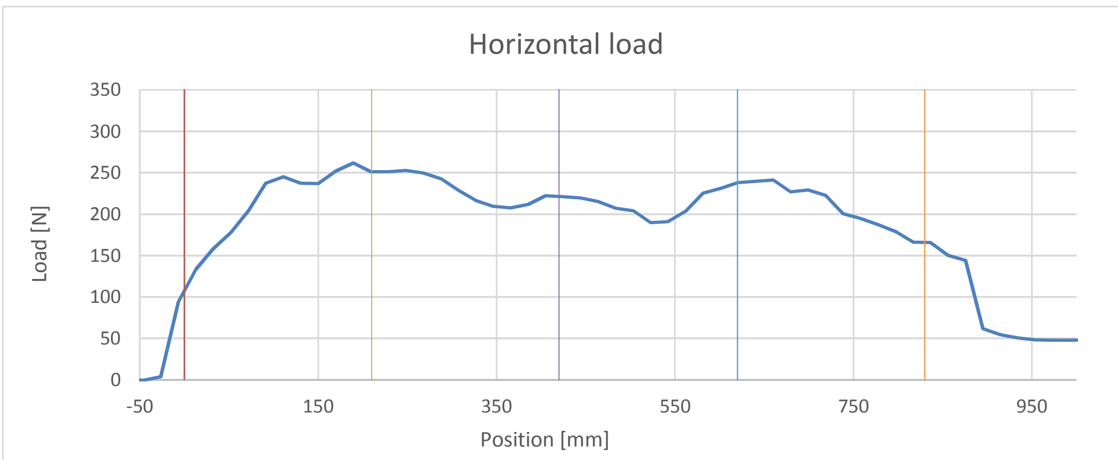
Remoulded measurements

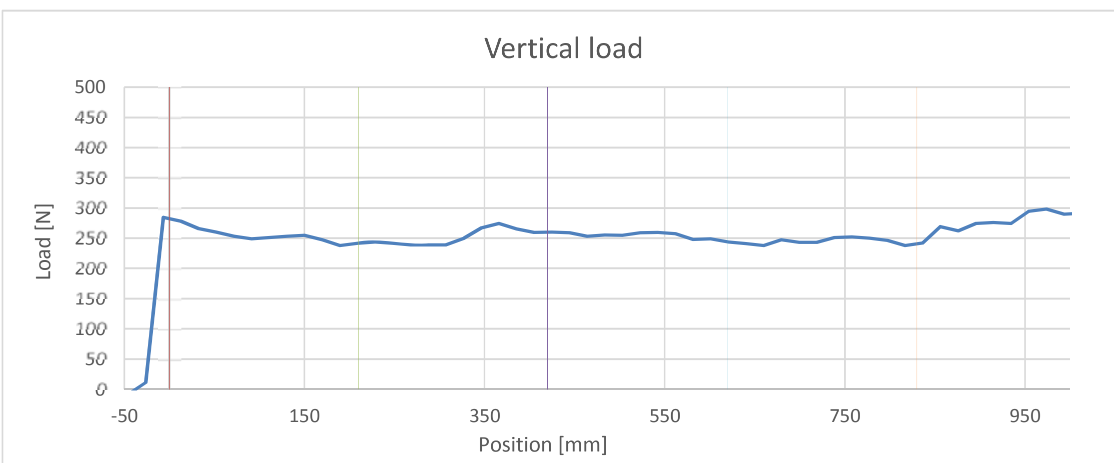


Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Longitudinal cross-section of the influenced area

Trench width of the plough

Cavity width of the nozzle

area of influence of the plough

Close up of the influenced area of the plough

Length of the clay being pushed forward by the plough

TEST REPORT 11

General information

Test number:	11
Date of test:	18-Jul-2019
Time of test:	14:47
Assistant during test:	Dhr. Kamminga

Test discription

Test eleven was conducted with the biggest nozzle of 14mm and a plough-nozzle distance of 45mm

the objective of this test is to see if there is a force reduction between the three nozzles.

Test Parameters

Nozzle diameter:	14	[mm]
Nozzle distance:	45	[mm]
Stand of distance:	10	[mm]
Jet pressure:	17	[bar]
Flow:	27,3	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

The jet nozzle failed to go through the entire clay block and only had a penetration depth of 50mm

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	53,0	[kPa]
Average shear strength**:	44,3	[kPa]
Average remould strength**:	26,7	[kPa]

After ploughing		
Average shear strength*:	49,3	[kPa]
Average shear strength**:	38,3	[kPa]
Average remould strength**:	22,3	[kPa]

*field vane
**hand vane

Averages in measuring length		
Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	313,1	[N]
Total Vertical load	188,6	[N]
Total force	365,5	[N]
Angle of total force	31,1	[Degree]

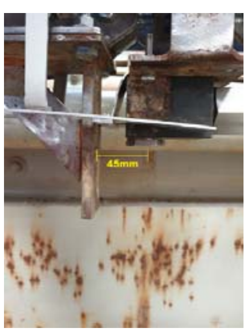
Remoulding measurements

Location	Shear strength	remould	Unit
Left plough	35	12	[kPa]
Middle plough	35	15	[kPa]
Right plough	39	20	[kPa]
Average	36	16	[kPa]

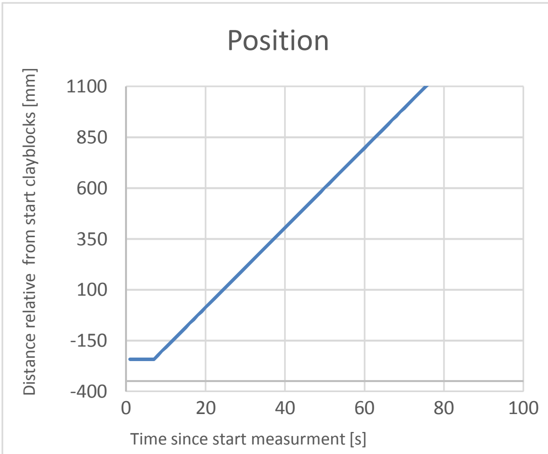
Remoulding conclusion

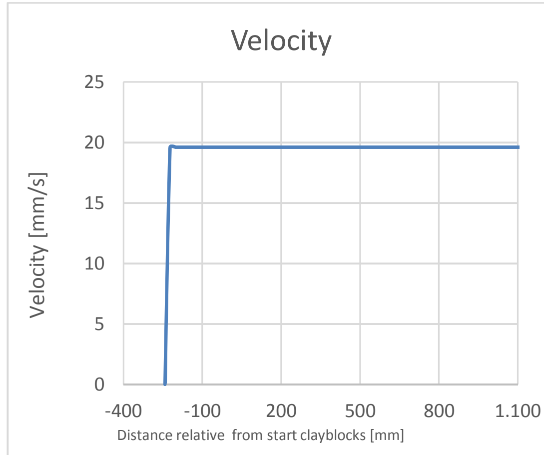
with a larger nozzle the influenced area is smaller then the other nozzles

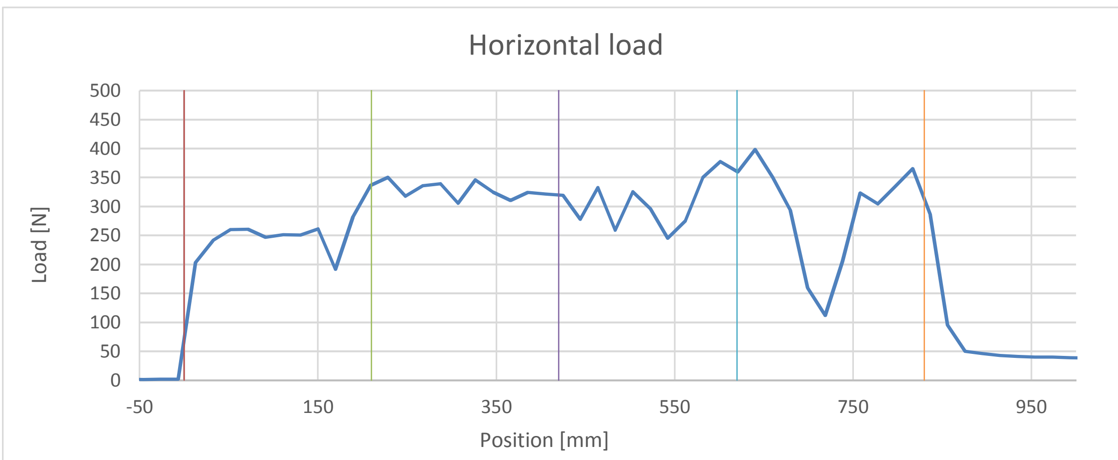
Remoulded measurements

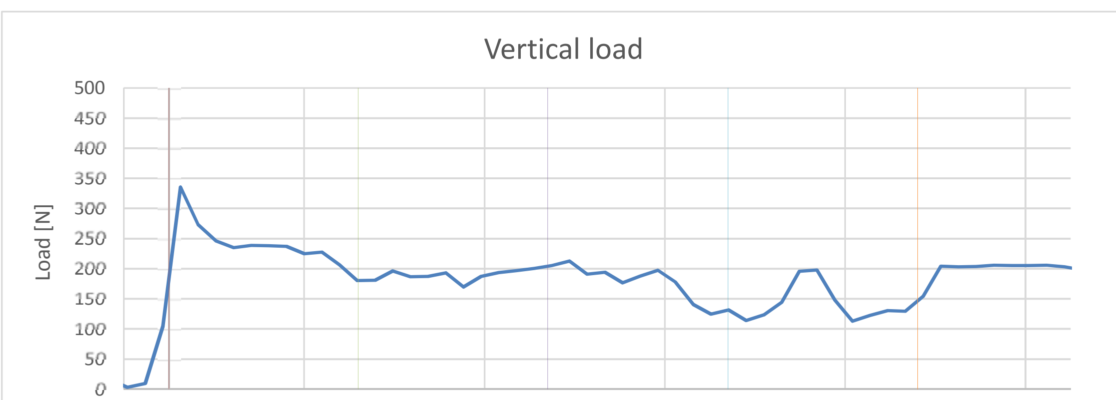


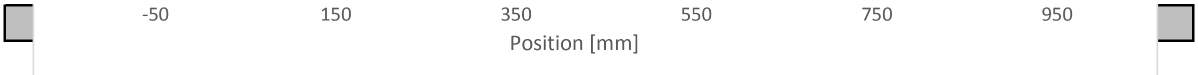
Measured results











Top view after ploughing

Side view plough after trenching

penetration depth of the nozzle

Trench width of the plough

area of influence

TEST REPORT 12

General information

Test number:	12
Date of test:	18-Jul-2019
Time of test:	17:17
Assistant during test:	Dhr. Kamminga

Test discription

Test eleven was conducted with the biggest nozzle of 14mm and a plough-nozzle distance of 45mm

the objective of this test is to see if there is a force reduction between the three nozzles.

Test Parameters

Nozzle diameter:	10	[mm]
Nozzle distance:	75	[mm]
Stand of distance:	10	[mm]
Jet pressure:	20	[bar]
Flow	15,8	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

The jet nozzle failed to go through the entire clay block and only had a penetration depth of 50mm

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	43,5	[kPa]
Average shear strength**:	40,3	[kPa]
Average remould strength**:	23,7	[kPa]

After ploughing		
Average shear strength*:	48,7	[kPa]
Average shear strength**:	37,7	[kPa]
Average remould strength**:	22,0	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	305,4	[N]
Total Vertical load	231,6	[N]
Total force	383,3	[N]
Angle of total force	37,2	[Degree]

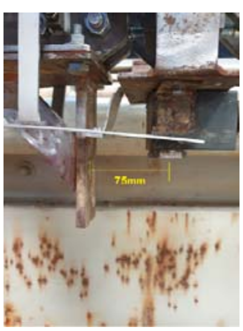
Remoulding measurements

Location	Shear strength	remould	Unit
Left plough	35	20	[kPa]
Middle plough	29	22	[kPa]
Right plough	38	20	[kPa]
Plough + 110mm	38	22	[kPa]
Average	35	21	[kPa]

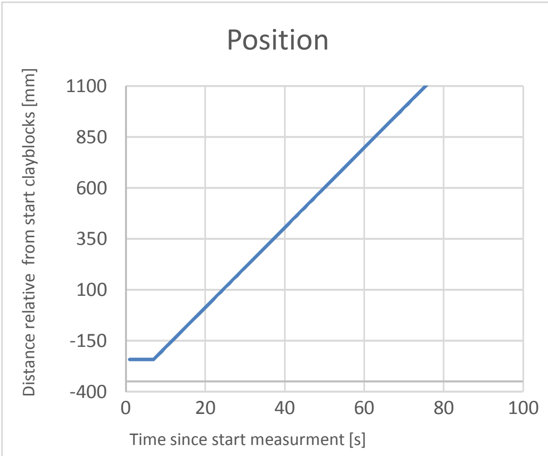
Remoulding conclusion

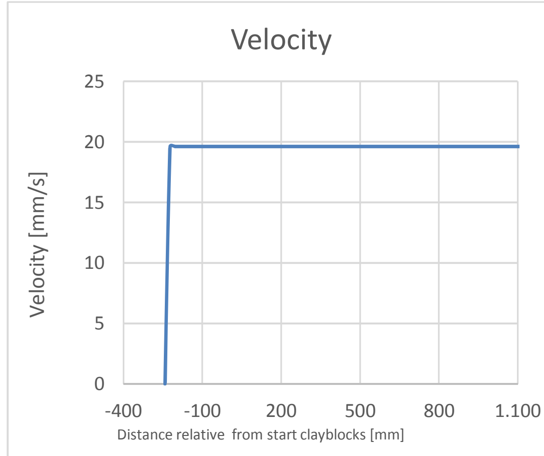
with a larger nozzle the influenced area is smaller then the other nozzles

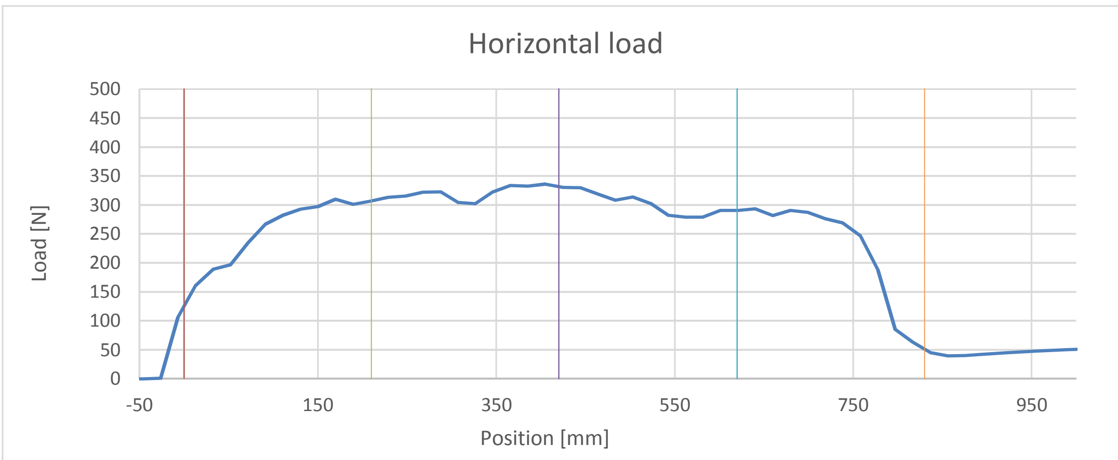
Remoulded measurements

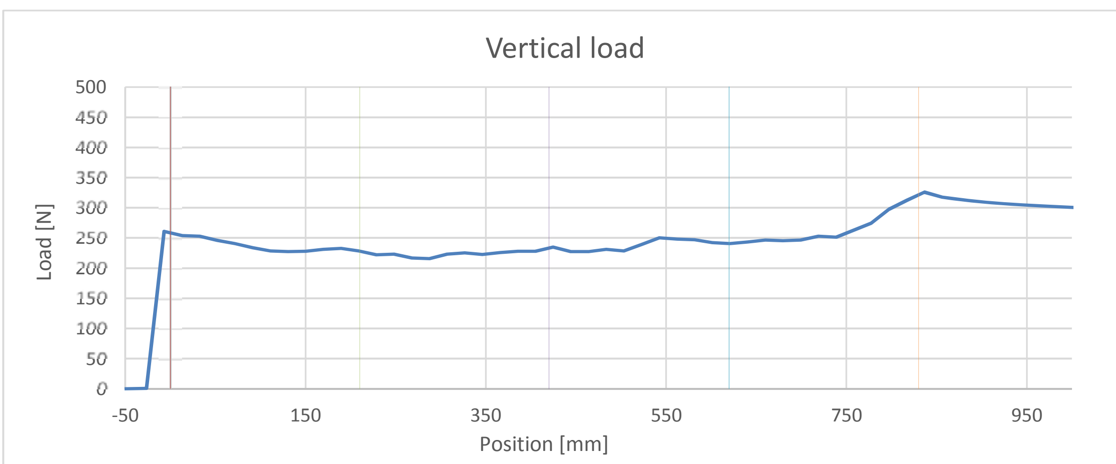


Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Cavity width of the jet

Trench width of the plough

Cross section bottom of jet nozzle

TEST REPORT 13

General information

Test number:	13
Date of test:	19-Jul-2019
Time of test:	12:04
Assistant during test:	Dhr. Burgel

Test discription

Test thirteen is the same test as 2 and 3 which is the 5mm nozzle with a plough-nozzle distance of 45mm

Because the valid test where all conducted with the new nozzle setup after test 6, the decission was made to also re-do this test so that all the tests were conducted with the same setup

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	45	[mm]
Stand of distance:	10	[mm]
Jet pressure:	32	[bar]
Flow:	5,05	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

No remarks

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	48,5	[kPa]
Average shear strength**:	40,0	[kPa]
Average remould strength**:	25,0	[kPa]

After ploughing		
Average shear strength*:	47,0	[kPa]
Average shear strength**:	44,3	[kPa]
Average remould strength**:	20,7	[kPa]

*field vane
**hand vane

Averages in measuring length		
Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	188,5	[N]
Total Vertical load	278,2	[N]
Total force	336,0	[N]
Angle of total force	55,9	[Degree]

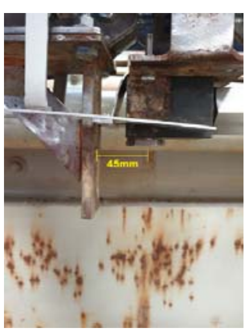
Remoulding measurements

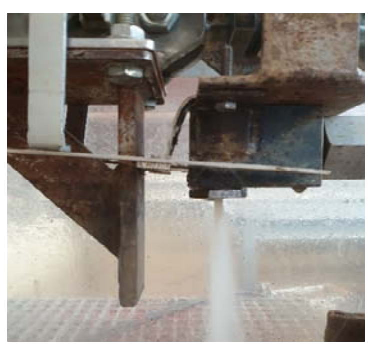
Location	Shear strength	remould	Unit
Left plough	40	22	[kPa]
Middle plough	30	18	[kPa]
Right plough	40	18	[kPa]
Average	37	19	[kPa]

Remoulding conclusion

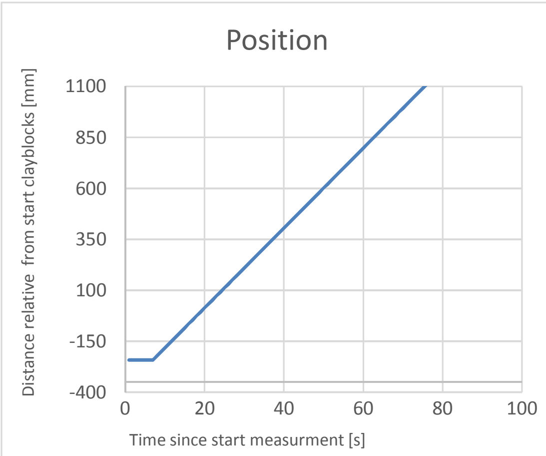
In the result of this test it was clearly visible that the plough pushes the clay back into the cavity made by the nozzle

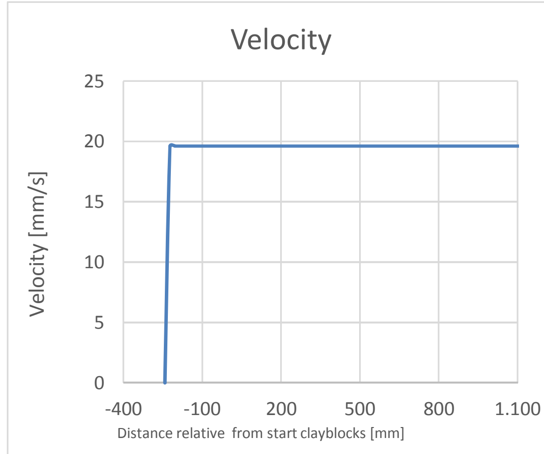
Remoulded measurements

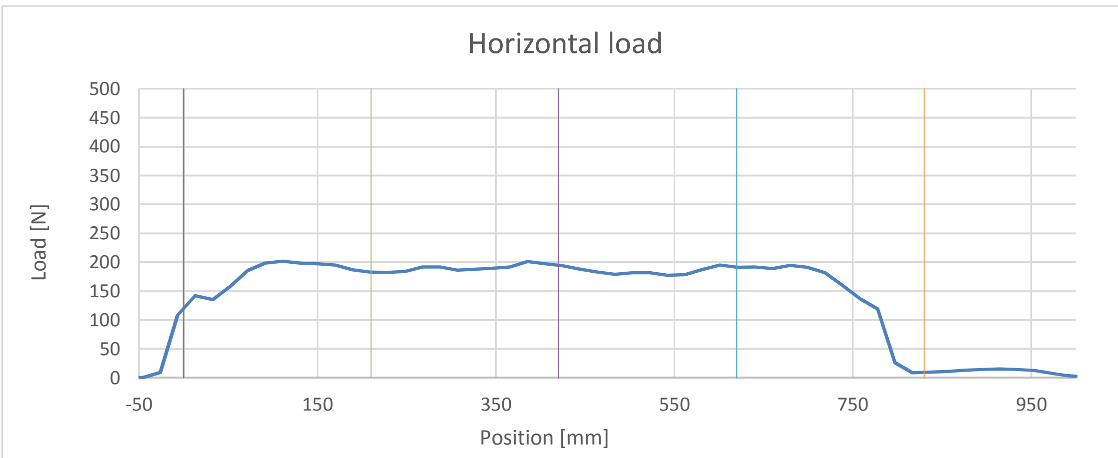


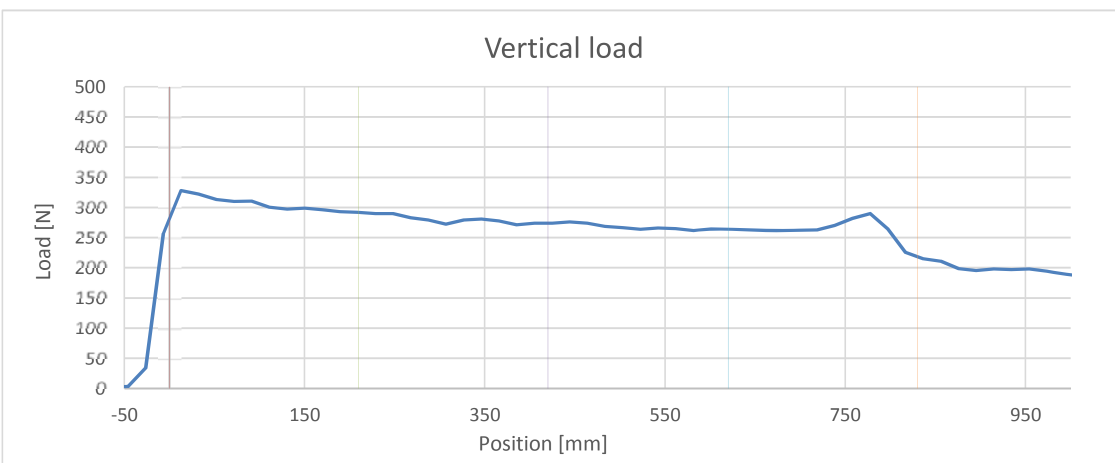


Measured results









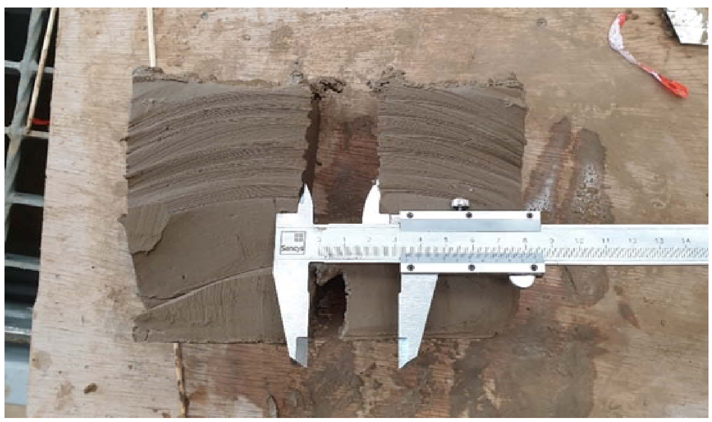
Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Cross section of the block with cavity width from the nozzle

Trench width of the plough



Width of clay being pushed forward by the plough

TEST REPORT 14

General information

Test number:	14
Date of test:	19-Jul-2019
Time of test:	14:21
Assistant during test:	Dhr. Burgel

Test discription

Test fourteen will be conducted with 10mm nozzle and a plough-nozzle distance fo 75mm

When sketching the graph of all the forces the both the 75mm nozzle where not as expected therefore the decission was made to re-do one of them and see if the results would like expected

Test Parameters

Nozzle diameter:	10	[mm]
Nozzle distance:	75	[mm]
Stand of distance:	10	[mm]
Jet pressure:	20	[bar]
Flow:	15,8	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

No remarks

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	42,5	[kPa]
Average shear strength**:	44,0	[kPa]
Average remould strength**:	21,3	[kPa]

After ploughing		
Average shear strength*:	42,0	[kPa]
Average shear strength**:	34,3	[kPa]
Average remould strength**:	17,7	[kPa]

*field vane
**hand vane

Averages in measuring length		
Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	230,6	[N]
Total Vertical load	278,5	[N]
Total force	361,6	[N]
Angle of total force	50,4	[Degree]

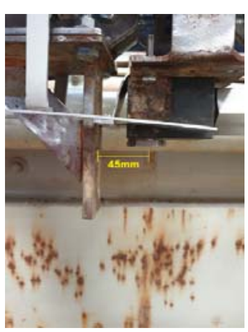
Remoulding measurements

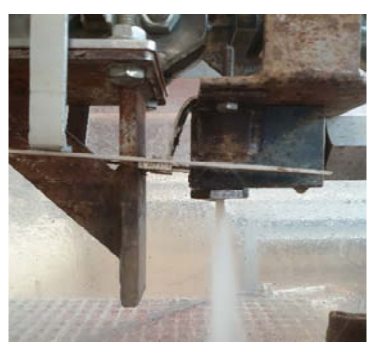
Location	Shear strength	remould	Unit
Left plough	40	22	[kPa]
Middle plough	0	0	[kPa]
Right plough	38	24	[kPa]
Average	26	15	[kPa]

Remoulding conclusion

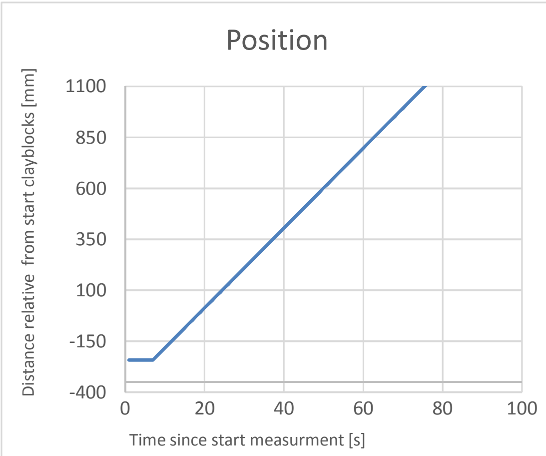
because of the larger nozzle the area of influence was small as you could see that their was hardly any clay being pushed upwards in front of the plough

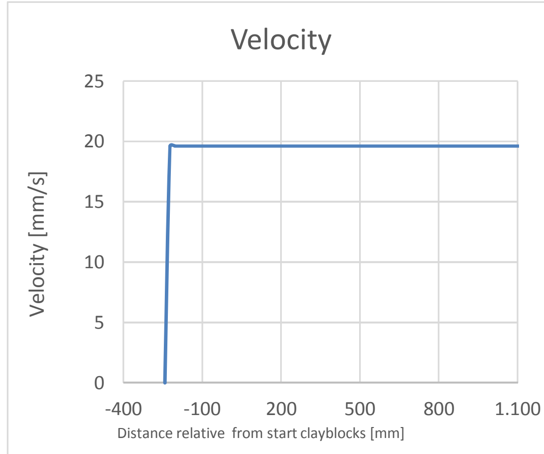
Remoulded measurements

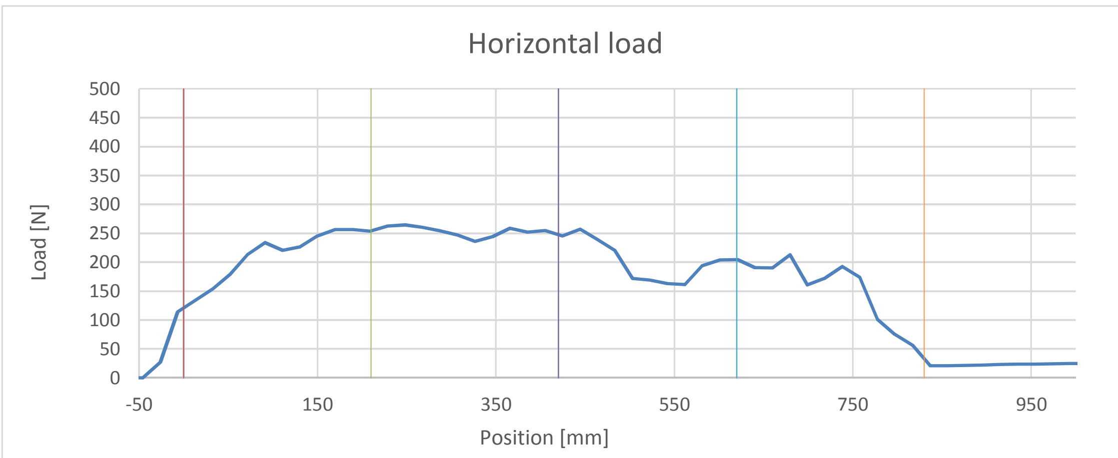


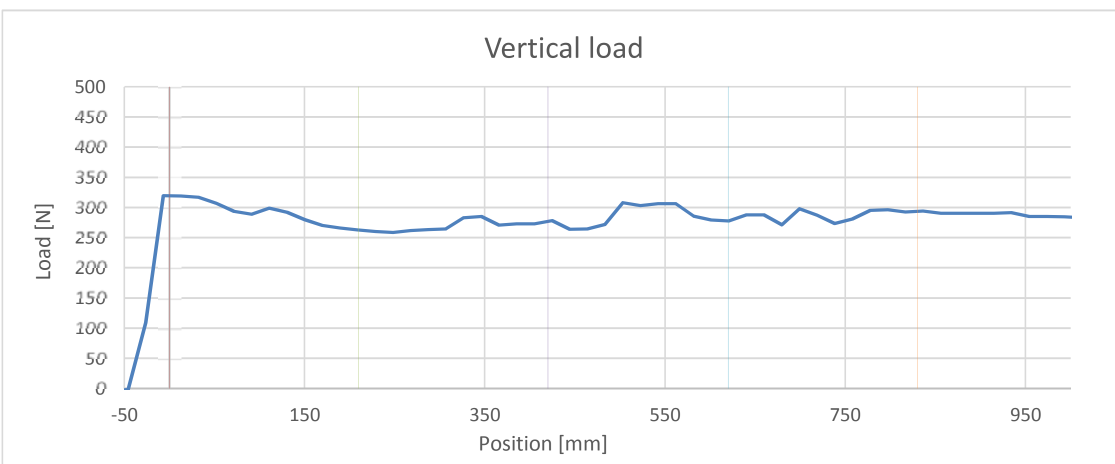


Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

view of the plough and nozzle still in the clay after the experiment

cross section view of the trench depth and the nozzle

Back view of the cavity created by the plough and nozzle

TEST REPORT 15 (A)

General information

Test number:	15
Date of test:	19-Jul-2019
Time of test:	16:59
Assistant during test:	Dhr. Burgel

Test discription

In test fifteen (A) only the 10mm nozzle went throught the clay to see what cavity width was

In test fifteen we used the 10mm nozzle on block 1&2 and in block 4&5 we used the 5mm nozzle

Test Parameters

Nozzle diameter:	10	[mm]
Nozzle distance:	0	[mm]
Stand of distance:	10	[mm]
Jet pressure:	17	[bar]
Flow:	15,37	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	0	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

During this test there was no plough attached to the spindel therefor bairly any forces are measured

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	51,0	[kPa]
Average shear strength**:	39,3	[kPa]
Average remould strength**:	20,7	[kPa]

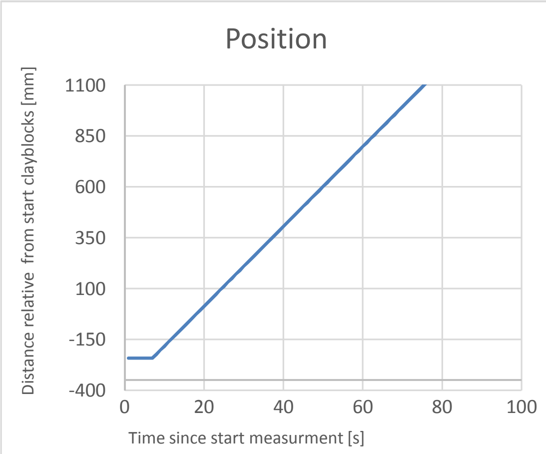
After ploughing		
Average shear strength*:	42,0	[kPa]
Average shear strength**:	35,0	[kPa]
Average remould strength**:	17,0	[kPa]

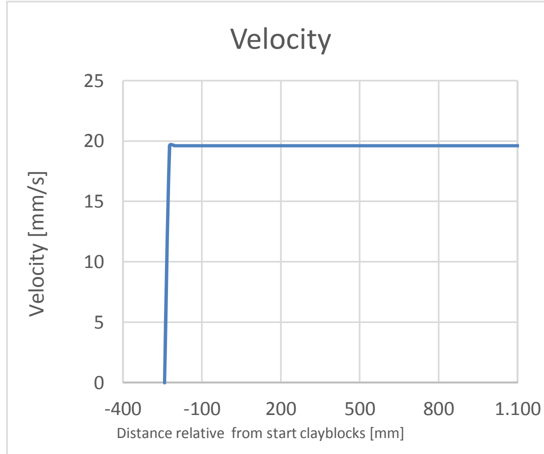
*field vane
**hand vane

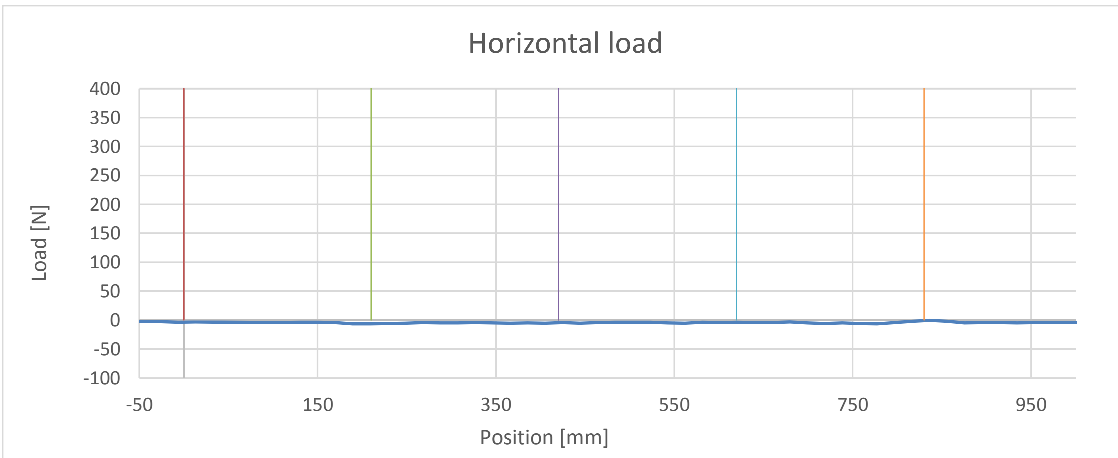
Averages in measuring length		
Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	-4,4	[N]
Total Vertical load	24,8	[N]
Total force	25,2	[N]
Angle of total force	-80,0	[Degree]

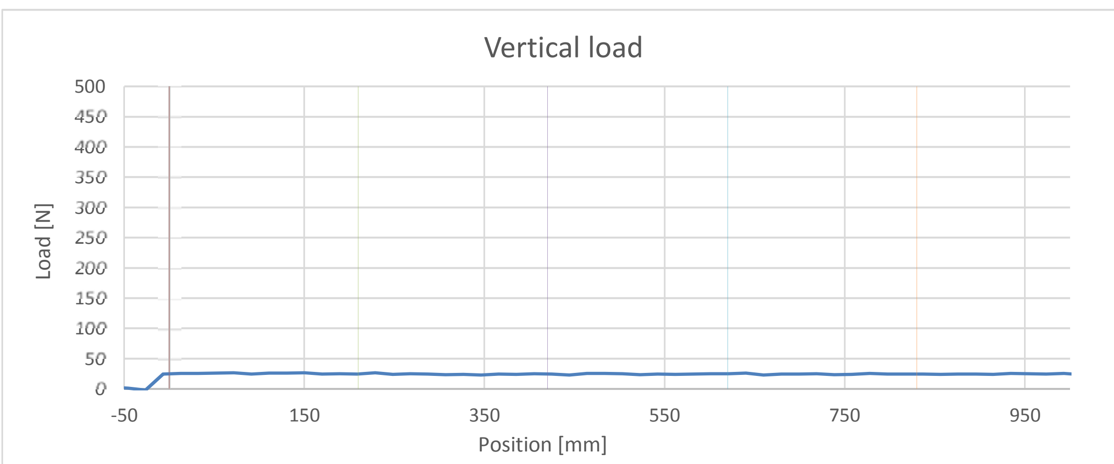
Plough model

Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

view of the plough and nozzle still in the clay after the experiment

cross section view of the trench depth and the nozzle

Back view of the cavity created by the plough and nozzle

TEST REPORT 15 (B)

General information

Test number:	15
Date of test:	19-Jul-2019
Time of test:	16:59
Assistant during test:	Dhr. Burgel

Test discription

In test fifteen (A) only the 5mm nozzle went throught the clay to see what cavity width was

The purpose of this test is to see what the cavity depth is created by the 5mm nozzle

Test Parameters

Nozzle diameter:	5	[mm]
Nozzle distance:	0	[mm]
Stand of distance:	10	[mm]
Jet pressure:	32	[bar]
Flow:	5,09	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	0	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

Cavity width: 22mm

Remarks during the test:

During this test there was no plough attached to the spindel therefor bairly any forces are measured

Material properties of the clay

Before ploughing		
Average shear strength*:	51,0	[kPa]
Average shear strength**:	39,3	[kPa]
Average remould strength**:	20,7	[kPa]

After ploughing		
Average shear strength*:	42,0	[kPa]
Average shear strength**:	35,0	[kPa]
Average remould strength**:	17,0	[kPa]

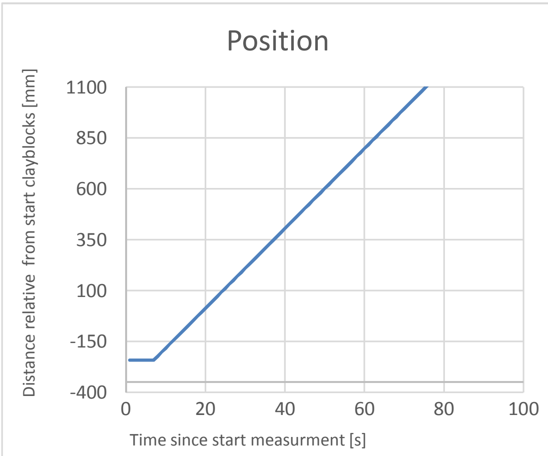
*field vane
**hand vane

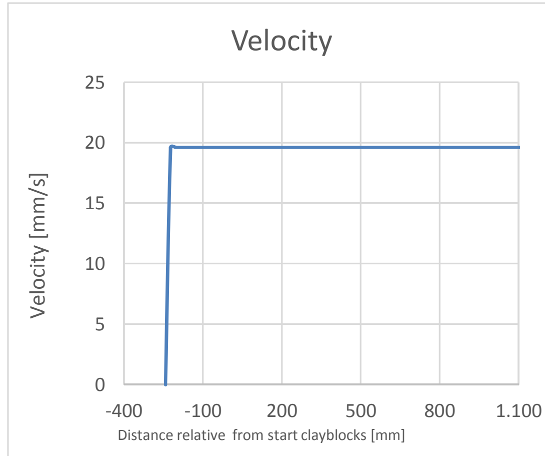
Averages in measuring length

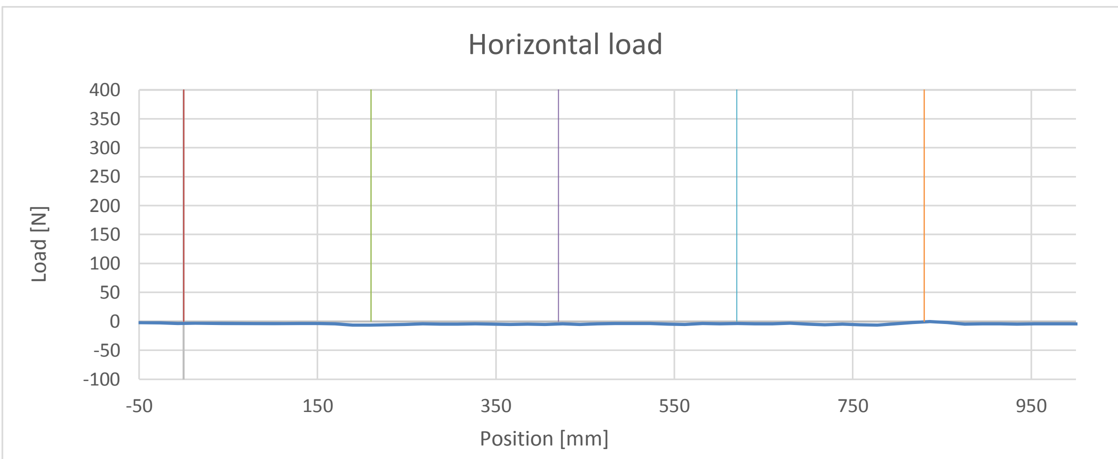
Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	-4,4	[N]
Total Vertical load	24,8	[N]
Total force	25,2	[N]
Angle of total force	-80,0	[Degree]

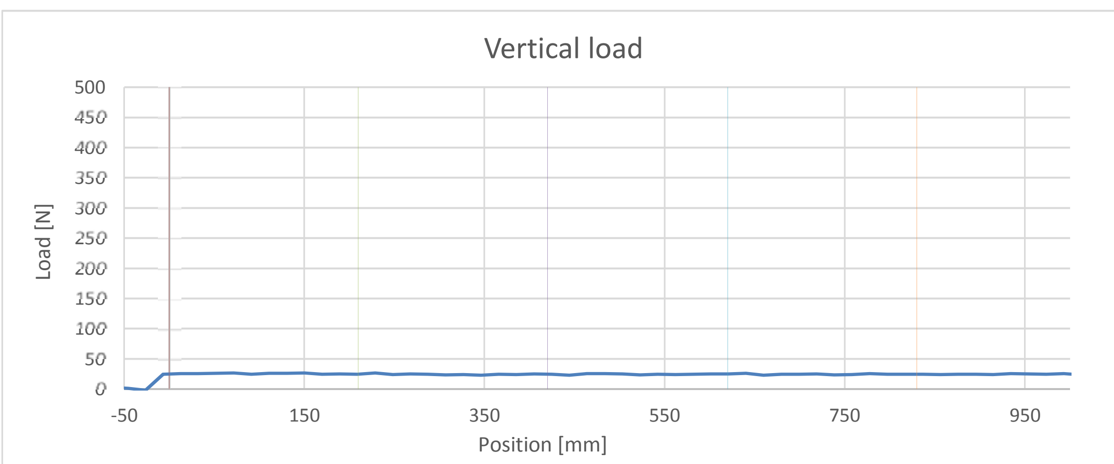
Plough model

Measured results





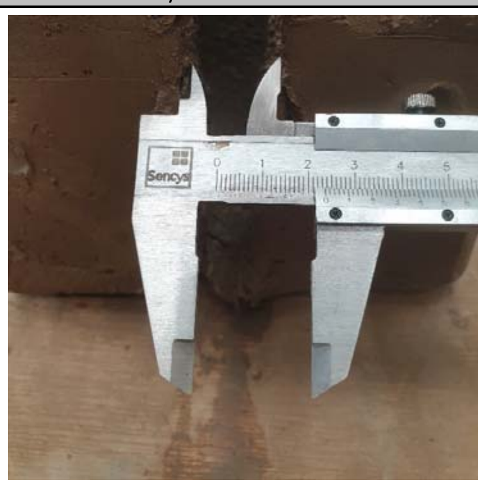




Clay block before ploughing

Top view after ploughing

Cavity width 5mm nozzle



Cavity width

longitude corss section of the cavity depth

TEST REPORT 16 (A)

General information

Test number:	16
Date of test:	21-Jul-2019
Time of test:	14:32
Assistant during test:	Dhr. Kamminga

Test discription

Test sixteen (A) was conducted without a nozzle, but with the cavity size created by a 10mm nozzle

The main objective of test sixteen was to see how many forces are acting on the plough if only the cavity of the jet is before the plough.

Test Parameters

Nozzle diameter:	0	[mm]
Nozzle distance:	0	[mm]
Stand of distance:	0	[mm]
Jet pressure:	0	[bar]
Flow:	0	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

For test sixteen (A) only the forces until 350mm into the clay was taken into account

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	46,0	[kPa]
Average shear strength**:	45,7	[kPa]
Average remould strength**:	20,7	[kPa]

After ploughing		
Average shear strength*:	48,7	[kPa]
Average shear strength**:	40,3	[kPa]
Average remould strength**:	20,0	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	278,8	[N]
Total Vertical load	339,0	[N]
Total force	438,9	[N]
Angle of total force	50,6	[Degree]

Remoulding measurements

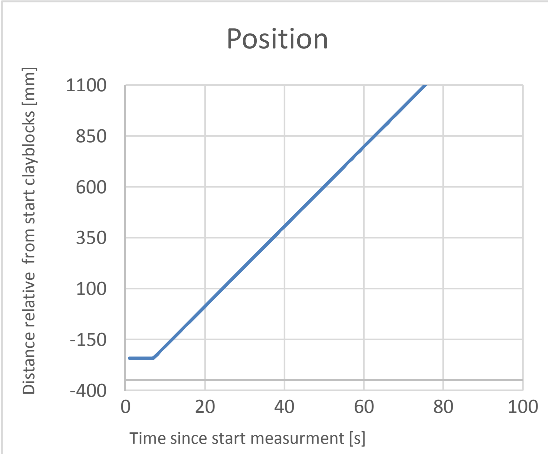
Location	Shear strength	remould	Unit
Left plough	45	20	[kPa]
Right plough	47	22	[kPa]
Average	46	21	[kPa]

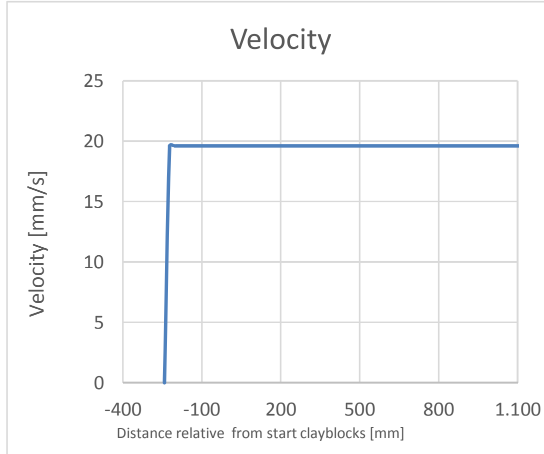
Remoulding conclusion

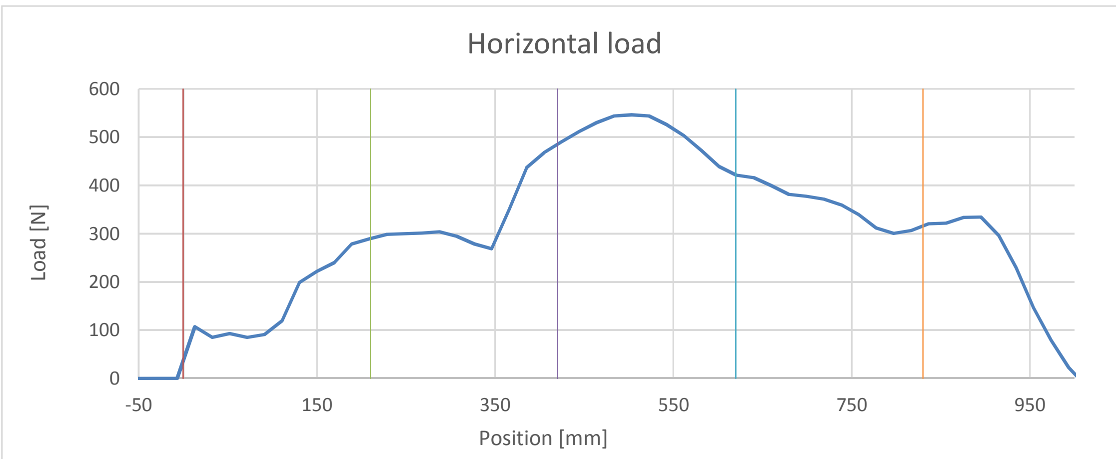
As expected the clay on the side of the plough was not influenced by the plough

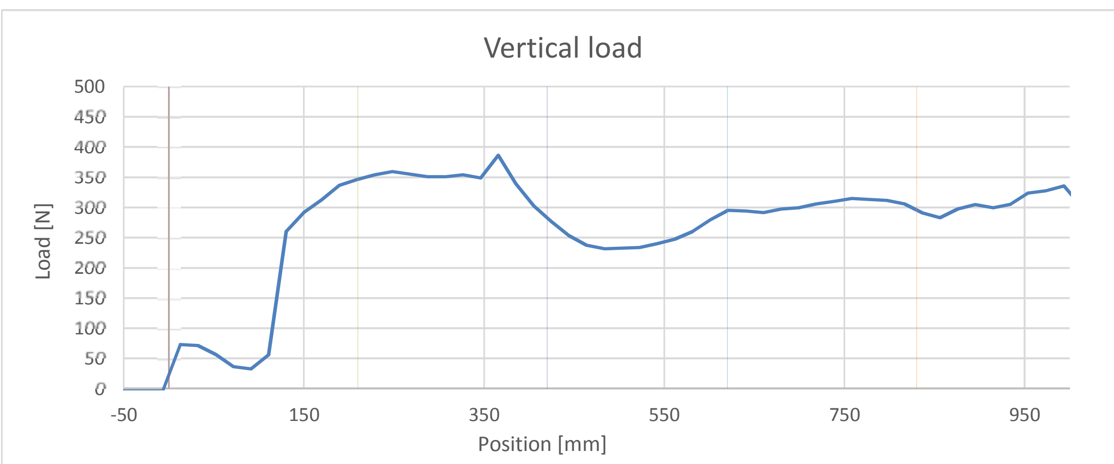
Plough model

Measured results









Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Cavity width before trenching

Top view after ploughing

Top view after ploughing

TEST REPORT 16 (B)

General information

Test number:	16
Date of test:	21-Jul-2019
Time of test:	14:32
Assistant during test:	Dhr. Kamminga

Test discription

Test sixteen (B) was conducted without a nozzle, but with the cavity size created by a 5mm nozzle

The main objective of test sixteen was to see how many forces are acting on the plough if only the cavity of the jet is before the plough.

Test Parameters

Nozzle diameter:	0	[mm]
Nozzle distance:	0	[mm]
Stand of distance:	0	[mm]
Jet pressure:	0	[bar]
Flow:	0	[m3/h]
Plough velocity	19,61	[mm/s]
Length of clay box:	1040	[mm]
Water on top of clay:	80	[mm]
Depth of the plough:	65	[mm]
motor setup:	-4	[-]

Test remarks

Pre/post-testing remarks:

For test sixteen (B) the forces from 650mm into the clay was taken into account

Remarks during the test:

no remarks

Material properties of the clay

Before ploughing		
Average shear strength*:	46,0	[kPa]
Average shear strength**:	45,7	[kPa]
Average remould strength**:	20,7	[kPa]

After ploughing		
Average shear strength*:	48,7	[kPa]
Average shear strength**:	40,3	[kPa]
Average remould strength**:	20,0	[kPa]

*field vane
**hand vane

Averages in measuring length

Start measuring length	-242,0	[mm]
End measurement length	875,6	[mm]
Total length	1117,6	[mm]
Average speed	20	[mm/s]
Average speed	70,6	[m/hr]
Horizontal load cell	338,2	[N]
Total Vertical load	302,9	[N]
Total force	454,0	[N]
Angle of total force	41,8	[Degree]

Remoulding measurements

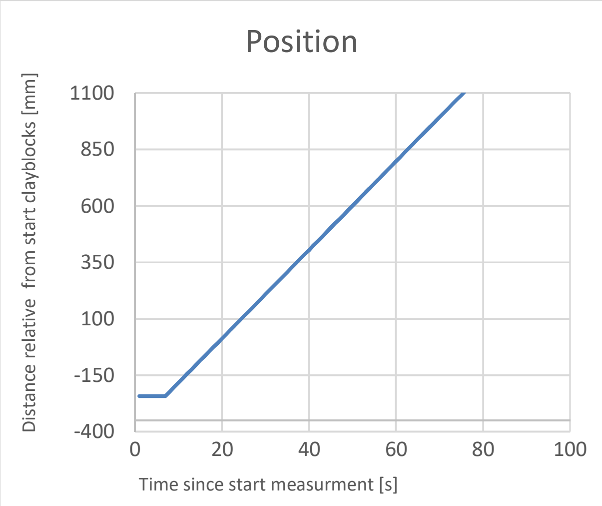
Location	Shear strength	remould	Unit
Left plough	45	20	[kPa]
Right plough	47	22	[kPa]
Average	46	21	[kPa]

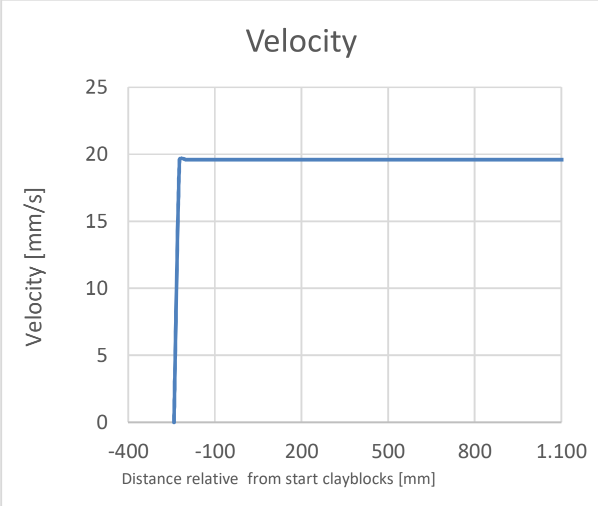
Remoulding conclusion

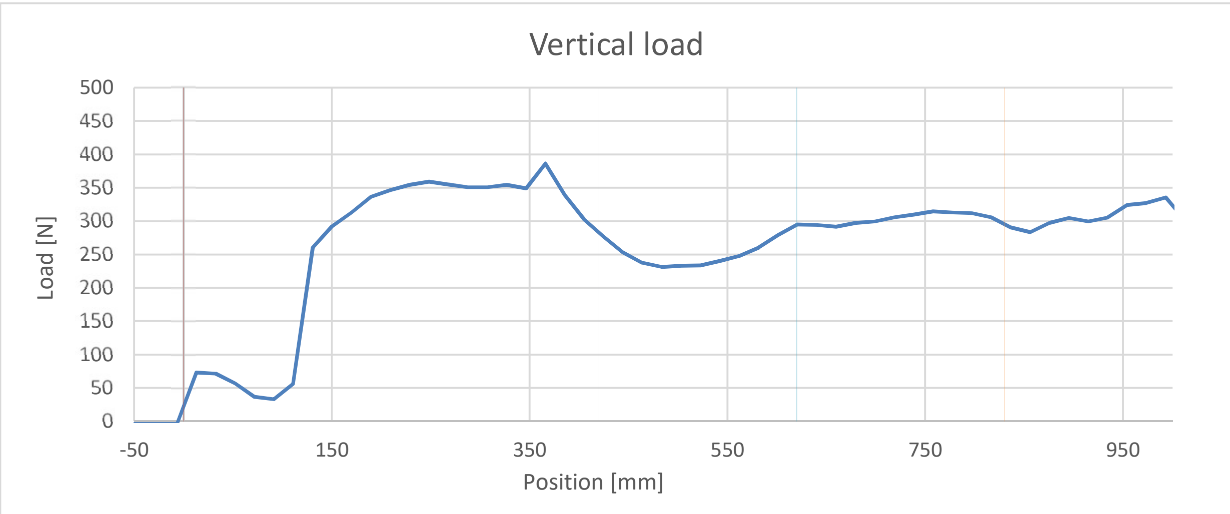
As expected the clay on the side of the plough was not influenced by the plough

Plough model

Measured results







Clay block before ploughing

Top view after ploughing

Side view plough after trenching

Cavity width before trenching

Top view after ploughing

Cross section the trench

APPENDIX F

Operational manual

OPERATIONAL MANUAL

Experiment test setup trenching

Royal Boskalis Westerminster N.V
15 august 2019

Document control sheet

Document title : Operation manual experiment test setup trenching
Document number :
Revision number : 1
Classification : -
Client : Boskalis research and development
Project code : -
Author : Mark Roos

Version		Author	Issue date	Remarks
01		Mark. Roos	15-09-2019	
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03				
04				
05				
06				
07				
08				
09				
10				

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Table of content

1. INTRODUCTION

1.1 Background

This manual was created in August of 2019 by a student in order to help future students to install and work with this experimental setup faster, efficient and safer. Because the test setup has lots of different components that need to be acquired from different companies and different departments within Boskalis it can be hard to know how acquire it.

This manual explains where and how to acquire the necessary equipment to install the setup. It also includes a walkthrough that explains step by step how to conduct the tests including some tips and risks based on the experience from using the test setup.

The experimental setup was designed and made in 2014 for the graduation thesis of Dhr, van Gurp with the help of Dhr, Biesheuvel. The test setup is used in different thesis which range from narrows shaped ploughs, to the design and development of the Burial sledge System III. Some of these topic where for the Subsea cable and Flexible division of Boskalis and some where for the Dredging department of Boskalis. Making this a versatile and indispensable piece of equipment that helps Boskalis in designing new equipment and improving the current equipment.

Table 1.1 Shows all the students and their topics that used the experimental setup during there research conducted in Boskalis

Name	Research title	Time frame	Pump present?
Wouter van Gurp	Development of a plough pulling force model for submarine narrow shaped ploughs	2014	No
Ezra Groen	Rotational jetting in clay	2015-2016	Yes
Gijs Kemperman	The operability of the burial sledge system II in cohesive soil layers	2016-2017	Yes
Erik Hoogeveen	Adhesion factor and reduction methods for subsea cables ploughing in clay	2017-2019	Yes
Mark Roos	Could the capability of the current trenching equipment be improved with the use of different jet nozzle setups?	2019	Yes

Table 1.1 List of the research conducted with the use of the test setup

1.2 Necessary equipment.

Not all equipment required for the tests is available at Boskalis, therefor some equipment have to be arranged from different companies or division within Boskalis. In paragraph 1.2 an indication is given where to acquire the necessary equipment. The list of items are based on the test conducted by M. Roos and should be checked at all time if they will also apply to your tests.

The equipment that is already purchased by Boskalis and are specific towards the experimental setup are marked with a yellow/green piece of tape on the items.

Central fleet support

To get all the necessary electrical components for the test setup an order has to be made by a engineer from the CFS (central fleet support) department of Boskalis. They will send this order towards the E&I department of Boskalis and will arrange an engineer that could install the equipment for you. The following items are required to install the electrical equipment but should be checked with an engineer of the CFS department if it's accurate for you.

- OPTO-22 manager box
- Distance meter
- 3x Loadcell (500kg)
- 7x 1,5mm^2 cable (5m)
- 4x 1,5mm2 cable (10m) data cable
- 1x Cat6 UTP patch cable
- 1 roll electrical tape

JB Hydraulic

Sportslaan 201, Sliedrecht

Phone: 088- 4040 500

When working with high pressure jets, hydraulic hoses are necessary to manage the pressure form the water. JB Hydraulic has all the equipment necessary from small links to hoses. There are two 10 meter hydraulic hoses in the hydro-lab that are being used in the experimental setup, these are indicated with the yellow/green tape and have blue/rad caps on the ends.

The necessary links can be find in the boxes found inside the holding tank and should at all times be placed back in the holding tank when not being used.

Van Dijk – Inpijn

Vlietskade 6007, Arkel

Phone: 018- 3566 666

When designing a new type of plough the company van Dijk-Inpijn is used to make the new ploughs. Other companies can also make the ploughs. Before placing an order the procurement department of Boskalis should always be asked if they have an order number for that company.

Rental pumps
Rosmolenweg 1, Papendrecht
Phone: 078- 6412 212

When tests with high pressure jets are conducted, a water pump can be rented from Rental Pumps. If the tests require low pressure jets Boskalis also has some pumps available for use. The Hydro-lab Manager knows more about these pumps.

When renting a pump from Rental pumps, it's important to know the necessary pressure head in order to get the correct pump. In the research of M. Roos and G. Kemperman a pump was used that can do tests up to 32 bar of pressure. In the appendix of their report a specification sheet of the pump can be found

Table 1.2 Shows the necessary items acquired from Rental pumps to connect the pump to the nozzle of the experiment.

Number	Name
255E02	Perspomp 2" elektrisch op skids B32/13c 22kw atex motor Zuig/pers: 2" flens
11111W2	Elektronische watermeter Dn50 PN16 Siemens
11029B	Frequentieregelaar tot 73A
	Drainage dompelpomp 1,5 – 2,2k W
	Zuig/koppelslang 2" x 6 mtr, perrot koppeling
	2" toebehoren Verloop 2" flens naar snelkoppeling 2" , M-deel
	64 ampère verlengkabel 20 meter

Table 1.2: Rented equipment from Rental Pumps

1.3 Safety

When entering the Hydro-lab in Boskalis, all people should be aware of the rules in this lab. This includes the use of personal protection equipment (PPE), the use of fire extinguishers and the locations of the emergency exits

- During testing you have to keep your safety glasses on
- When the crane is being operated everybody should be wearing a safety helmet
- When working in the hydro-lab all people involved should be wearing a coverall and safety shoes

Tests can be performed with high pressured nozzles. When working with the pump everybody in the direct area has to wear safety glasses. Before the test starts everybody should be aware of where the emergency switch is in case something will go wrong. To minimize the risk for something to go wrong the following actions will be taken.

- The frequency inverter on the pump will be at 0 at the start of the pumping

- All connections and bolts will be checked if they are correctly tighten
- Check if the nozzle is free of movement
- Check if all the hose are lying correctly
- Make sure that everybody is aware when the pump will start

1.4 Acquiring clay

Acquiring the correct clay is not as easy at it seems because there are only a couple of companies in the Netherlands who could help you with it. Before ordering the clay it is advised to go towards the companies and see if the clay meets the necessary requirements. Most of these companies are roof file factory's and they do not need the shear strength properties of the clay. By going towards the companies and checking it with a hand vane you make sure that the clay meets the requirements you need. In the report of W van Gurp there are a couple of options on acquiring clay mentioned and the list below are companies that are previous used to order clay.

Ginjaar Kleiwaren

Doeslaan 32-38, Leiderdorp

phone:071- 5895 329

M. Roos and E. Groen both acquired there clay at this company. The clay they supply is pottery clay with a shear strength of 45 kPa. The clay is distributed in block of 0.15*0.16*0.21 m.

Wienerberger Tegelen

Trappistenweg 7, Tegelen

Phone: 088- 1185 800

G. Kemperman acquired his clay from this company. The clay was distributed in large blocks of 0.16*0.16*1.05 m and had a shear strength of 120 kPa.

Wienerberger Deest

Munnikshofsestraat 4, Deest

088- 1185 800

W. van Gurp acquired his clay from Wienerberger Deest, the clay consisted out of block from 0.15*0.16*0.21m and had a shear strength of 45 kPa.

1.5 Risks

- Some steps will require the use of the overhead crane. When these steps will be conducted people are mandatory to wear helmets and have to be aware where the crane is lifting at that current moment.
- High pressured jets will be used during the experiments. When the jets are turned on everybody in the surrounding area should be wearing safety glasses.
- Because there is water and electricity involved all cables should be checked. if the electrical wires are not exposed to prevent electrocution.
- During the test nobody is allowed to hang above the frame due to moving parts on the test.
- With the use of clay, people should be careful where they walk. If there is clay on the floor there will be an increased chance of slipping. To prevent this, clay will only be used on top of the red bin, so that all excessive clay will fall into this bin and not on the floor.

- Risk of flooding. Due to the location of the test setup, there is a chance that there is water coming from other test setups that can flood the work location. To prevent this the other test setup will be checked on leakage.
- With the wires from the measuring devices, people should be conscious to not trip over these wires. To minimize this risk, all cables will be bundle.
- Because the experiment will be conducted with clay and water all people should be wearing coveralls to prevent clothes from getting dirty.

1.6 The test setup

To correctly set up the experiment, a sufficient amount of area is necessary. Therefor the experiment layout should be placed in consultation with the hydro-lab manager. To effectively use the limited space in the lab a couple of things can be done to save space. Use pallets or a steel frame to place the water pump on top of the water. This way you can save some space. Another option is to use the wooden planks to make a floor on top of the flume. These wooden planks and steel beams can be found at the end of the flume. In figure 1.1 is an example given of how the test setup can look with all the necessary components to conduct the tests.

1. Clay storage
2. Clay preparation area
3. Top frame storage
4. Experiment location
5. Control panel water pump
6. Water pump
7. Water storage

Figure 1.1: topview of the test setup

2. PRACTICAL TEST SETUP

2.1 Installing the dredging datalogger

In order to retrieve the data from the sensors a dredging logger has to be installed on your laptop. The dredging logger program can be acquired through the Boskalis R&D general department located in building 2. The installation steps in this manual are specifically for the installment of the datalogger to be used on the trenching experimental setup. For more specific information about the dredging logger, an additional manual is available named "*Field user manual v4 CIT datalogger 13-07-2004*".

When opening the datalogger the following screen will appear. This is the main menu with the location shown where the file is saved and the three main groups configuration, acquisition and monitors.

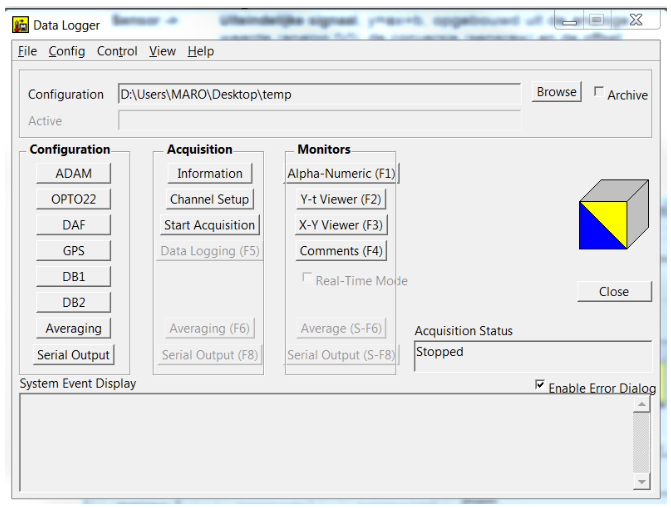

Figure 2.1: Main menu datalogger

First a new configuration file has to be made. This can be done by going to File > New > save as. Once you have made a new file go to Config > OPTO22 and fill in the screen that pops up as

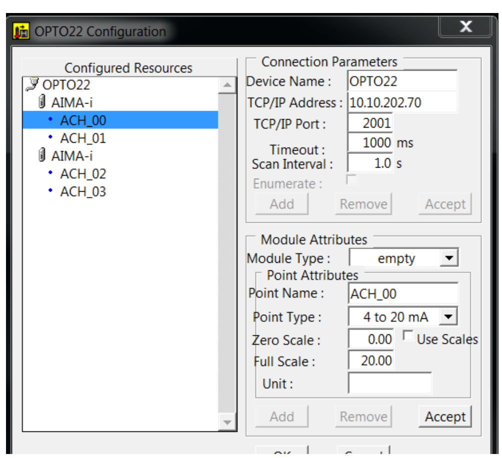

Figure 2.2: Configuration screen

shown in Figure 2.2. When the sensors are correctly inserted into the OPTO box, the channels should become visible in this screen.

- TCP/IP Address: found on the back of the OPTO box
- Scan interval: Own preference (recommended 0.1 or 1 s)
- Point type: Signal range found on the sensor.
- Press add and accept to make the setup go to the configured resources
- Repeat this action with all channels until they all added.

TIP: Check if all the channels are correctly added, sometimes the setup is not added. If this happens close the datalogger and reopen it.

Once all channels are correctly added go back to the main channel and go to channel setup under Acquisitions, the following screen will appear.

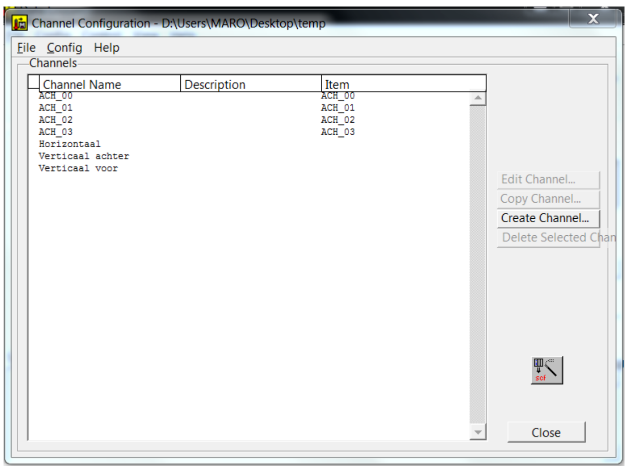

Figure 2.3: Channel configuration

Press the grey square in the bottom to go to the channel configuration. And create new channel.

In the channel configuration you can change the name of the channel, if you go to connection you can change your typ to either input or calculation.
In the example in Figure 2.3 the ACH channels are configured with typ, this will give your results in mA and have to be converted in excel to the desired unit.

For the "V*ertical achter*" channel the calculation option was used. As shown in Figure 2.4, this calculation was used to convert the mA into Kg, so that there was an indication on what the forces are in Kg. In order to get the values the Boskalis R&D department has an excel sheet called "*ijken sheet"*. This sheet is a handy tool to use for the calibration of the sensors.

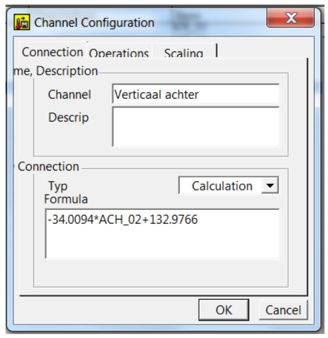

Figure 2.4:Calculation to convert to kg

Once this is setup you can close the interface and go back to the main menu of the dredge logger. When clicking on the start acquisition the program will collect the data form the sensors and will show these under the tab Monitors > Alpha-numeric (F1).

2.2 Calibrating the sensors

In order to have good test results the sensors have to be calibrated. The Boskalis R&D department has an excel sheet called "ijken sheet". In Figure 2.4 a part of the calibration sheet is shown. In order to get the correct calibration the yellow parts have to be filled in manually. Under 0 kg you have to put down the value of the sensor when nothing is attached. Next up you add some weight on the sensor (in this example 21.8 kg) and write down the value the sensor gives with the weight attached to it. The difference part is to check if all the sensors have the same deviation.

The values given by the formula "*Kg = a*mA+ b*" are put into the calculation part mentioned in paragraph 2.1, or can be used in the excel sheet to make the conversion from mA to Kg or Newton in excel.

VERTICAAL ACHTER (ACH02)			500kg
kg=a*mA+b			
			Difference
mass (kg)	0	21,8	
mA (signal	3,91	3,269	0,641
a=	-34,0094		
b=	132,9766		

Figure 2.5: Part of the calibration sheet

When the sensors are calibrated the test setup is ready to be used.

3.PLAN OF APPROACH

3.1 Introduction

In chapter three all the necessary steps will be explained in order to conducted the tests. The steps are based on the experimental setup of M. Roos which was a test setup that used a water pump. The required steps can vary for each topic and have to be checked if it suits the goals of your experiment.

During each step some tips will be mentioned to perform the step easier and more efficient. The risks will also be mentioned so that you are aware of what to expect and where to pay attention to when conducting the step. In Chapter 4 there is a summary of all the risks that could occur during the test procedure, which need to be known to everybody who is helping with the test.

3.2 Test procedure

The following steps have to be taken in order to perform the test correctly and safely. All steps are based on the insight of using the experimental setup and can differ based on your own preference or test sequence.

Step 1

The first step to start an experiment is to fill the clay box with the required clay. Before preparing the clay box a couple preparations have to be made. As shown in Figure 3.1 a wooden plank was put in the box in order to have the plough go through the middle of the clay to give the best test results. If you have to jet through the entire clay block, it is advised to make a wooden frame where the clay can be put on. This is necessary to get rid of the surplus of water created by the jet. There are two clay boxes, one has a part of the steel headplate cut of, this was done so that more water could be flushed away when the jet nozzle is active. An example of the wooden frame and steel headplate in cut can be found in Figure 3.2.

Depending on the selected clay the following tools are required to finalize this step.

- Carpenter square
- Steel wire
- Hand vane & Field vane
- Torque wrench
- 2x 1 meter lifting sling

If the clay block is selected it is necessary to have a flat surface to prepare the clay. With the use of a carpenter square all the planes of the clay block are flat. This is needed to make sure that there are no air pockets between the clay block which can influence the results. When the clay is firmly placed in the holder, use the movable side wall to hold the clay in its place. Make sure that the wall is perpendicular to the bottom plate. Once the clay is firmly locked, the surplus of clay can be removed using a steel wire. Once the clay is removed the shear strength measurements can be done using the hand vane and field vane.

The clay box is now ready and can be transported using the lifting slings and the crane into the holding tank. Make sure you do this with two persons, because the plexiglass windows are fragile and can break easily.

Figure 3.1: Top view of a prepared clay box

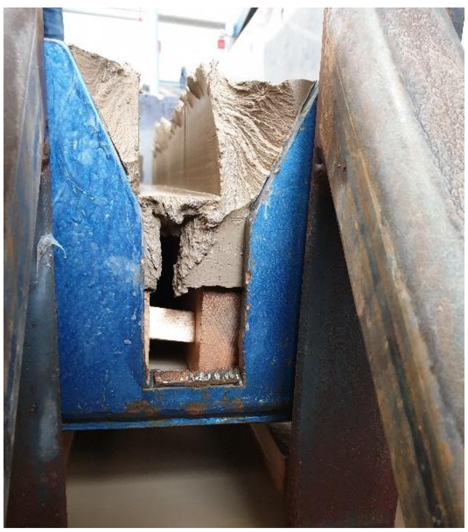

Figure 3.3: Opening for water removal

Figure 3.2: Wooden frame for water removal

TIP:

- Use packaging foil between the clay and the clay box, this makes removing the clay afterwards easier.
- Use a small wooden plank to make the top of the clay box flat, this is the easiest and fastest way.
- When not using the carpenters square and steel wire, put them in a bucket of water so it's wet and less clay will stick on to it
- Push the straps used to lift the clay box in its position under the clay holder, once the box is in position its hard to get the stress out of there.

Risk

- Make sure that the straps are firmly put under the clay box, if they are not correctly put under the clay box they could float once the holding tank is filled with water and could entangle in the plough.

Step 2

Once the clay box is in the correct position the top frame can be placed on top of the holding tank. In order to operate the crane safely two people are required. Because the most weight is on the side of the motor the crane has to lift the frame asymmetrical. Figure 3.4 Shows the best option to lift up the top frame.

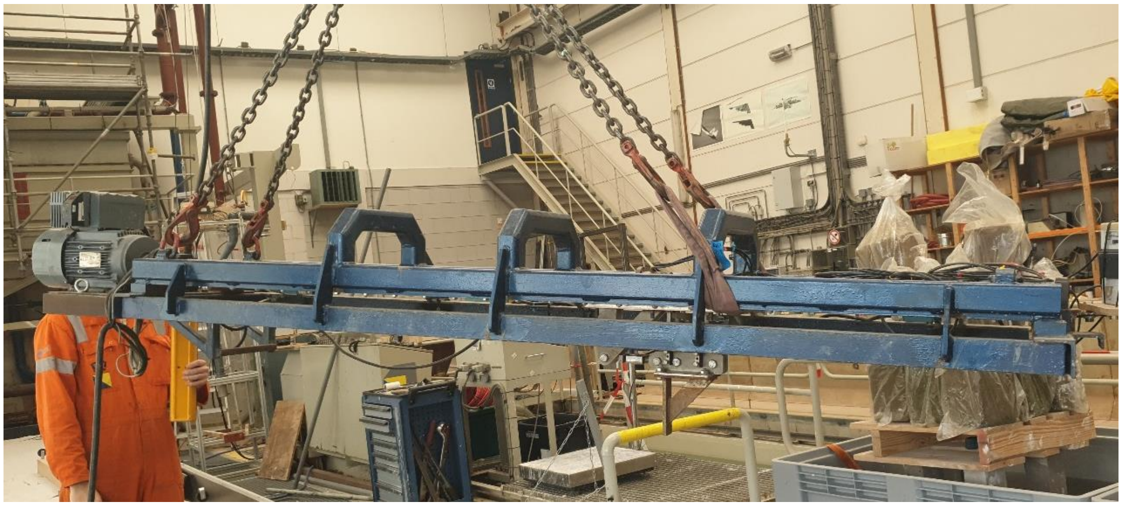

Figure 3.4: Best method for lifting the top frame

When lifting the frame the following points have to be checked in order to be placed correctly and safely

- Make sure that the cables hanging from the sensors are freely to move with the frame and can't get stuck behind anything.
- Make sure that the plough is higher than the holding tank, if the plough would hit the tank it could break the tank or the plough itself could break.
- When placing the top be careful with the last couple of centimeters. The wooden frame has to fit exactly between the bolts on the frame, it can only fit in one way.
- When having a wide plough make sure that the top is push all the way to the back. Figure 3.5 shows the arrow that indicates to what side to push the top. Before disconnecting

Figure 3.5: Push indication

check if the cables from the sensors are in the correct position and not under the frame, if so they can break.

Tips:

- To minimize the risk during this step go slow, and double check everything.

Step 3

Step three is an optional step which only has to be performed when a pump is being used during testing. The step can also be performed before step 2 but it's more convenient to do it after step 3.

The best time to connect the hose to the cart is after the top has been placed. It can be done before the top has been placed, but it's easier to connect the stiff hose after the top is on its place. It is advised to keep the hose and the nozzle holder connected during the whole testing period because then it's easier to have the nozzle linear to the steel plate and easier to attach to it. After the nozzle is attached you can plug in the pump and fill the holding tank. During this step it is advised to also install and turn the camera's on if necessary. When filling the holding tank with water make sure to check the height of the overflow. The overflow should not be higher than the horizontal sensor. The sensors are able to withstand water, but its advised to keep them above the water level.

Tips:

- Use a socket wrench and a normal wrench (size 10), this makes it easier to tighten the bolts in the limited space inside of the holding tank.
- Put the bolts in a small cup of water in between tests, if not the sand/clay in the thread will become hard and it will be harder to tighten the bolt.
- Advised is to move the flow until the front of the clay box, to check if the plough doesn't hit the clay box.

Figure 3.6: Hose to nozzle connection

Step 4

All the safety checks are done in step 4 and should be done at least twice to make sure all the safety measurement are taken. The check can be done I any particular order but the next one was my own preferred order. To do all the checks a second person is required to help and assist, this person also needs to know about all the checks so that he can verify if all the steps are done correctly.

- Turn on the datalogger by pressing ‘start acquisition’ and ‘data logging’. If data logging is not turned on it won’t record the measurement!
- Plug the electro motor. It can occur that the fuses are turned off, in that case turn the fuses back on (group 19). .
- When you are at the fuse box also turn the switch for the pump control box on.
- Check if the motor is on the correct speed and direction.
- Turn on both submersible pumps.
- With the chance of spilling water, check if no electric devices are close to the experiment, especially when using larger nozzles.
- Go over the plan and points of attention during the test with the lab partner. So that it is clear what to watch out for and what to do. For example:
    - What to do when something happens?
    - Where is the emergency switch?
    - What is everybody’s role during the test?
    - Any special thing during this test?
- Turn on the water pump. This step requires two persons. One person has to turn the power of the pump up, and the other has to be at the pump and check the pressure until it’s at the required level.
- Double check if the datalogger is operating correctly.

If all checks are done correctly the test can start.

Tips:

- Try to have the same lab partner during all tests, this way you can go faster through all the tests and this can save you a lot of time in the end.
- Take your time the first couple times to get familiar with the procedures.
- Inform your lab partner correctly so he is prepared on what could happen.
- Save a new *“config”* file in a different map every time. This way the data from the test is easier to find.in case the data export from the datalogger goes wrong.

Risks:

- For this test you are working with high pressured jets and electricity close to water, so make sure that everybody is wearing the required PPE.

Step 5

Once all the checks are completed the test can be executed. In order to do the tests safely its mandatory to be with at least two persons. Each individual should be aware of the goal for the particular tests and should know what to do if anything unexpected happens.
During the test one person should always hold the cables from the sensors, because these cables are hanging unprotected and there is a large risk that the cables could get stuck between the wheels of the cart and could break. This mainly happens when you drive the cart back to the starting position.
When the test is operated with an nozzle the second person should watch the hose connected to the nozzle. Because this is a stiff cable there is a possibility that the hose could hit the on/off switch and this would results in an incomplete test. This person should also always have its hand close to the on/off switch on the outside of the tank, in case something goes wrong he can quickly turn it off.

When the test is being performed, its mandatory to wear safety glasses when close to the holding tank and its forbidden to have your hands in the holding tank when the jet nozzle is turned on.

Tips:

- When operating with higher pressures on the jet, it's advised to have something against the spilling of the water, so that no electric equipment becomes wet. There are some wooden planks made that fit in the holes of the guidance rail, who prevent water from spilling. Figure 3.7 shows how the wooden planks have to be fitted.

Risks:

- Breaking of the electro cables when not correctly guided.
- When the test is running it's not allowed to have your hands inside the holding tank.
- Operating with high pressured jets contains dangers and everybody should be informed about these risks.

Figure 3.7: Wooden planks against the water

Step 6

After the test is conducted turn of all the equipment, save and turn the data logger off at the laptop. With the following steps you can save and export your information so that it can be transferred to Excel

When the test is conducted go back to the main menu, if you are on the main menu the screen should look like Figure 3.8.

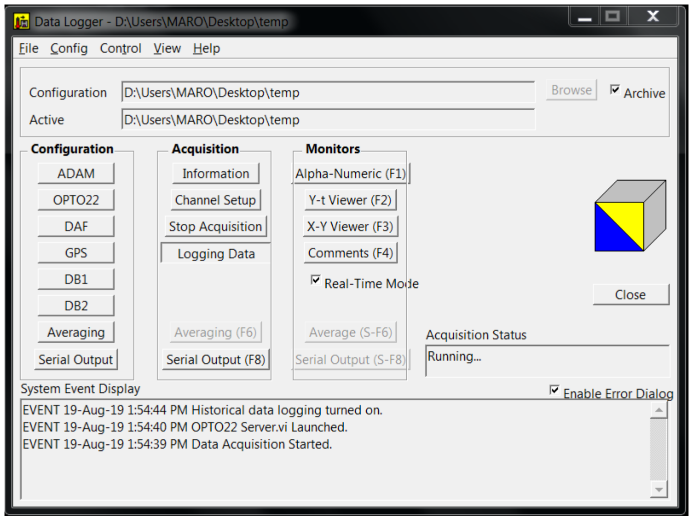

Figure 3.8: Main menu of the data logger while operating

If you press logging data it should change back to data logging (F5), next you press 'Stop Acquisition' and the program will acquire all the data. Once the program is done with the gathering go to File > Export and the screen in Figure 3.9 is shown. In this screen make sure that all the sensors that are used during the tests are selected. The start and stop time should be filled automatically if you use a new config file in a new folder every time.

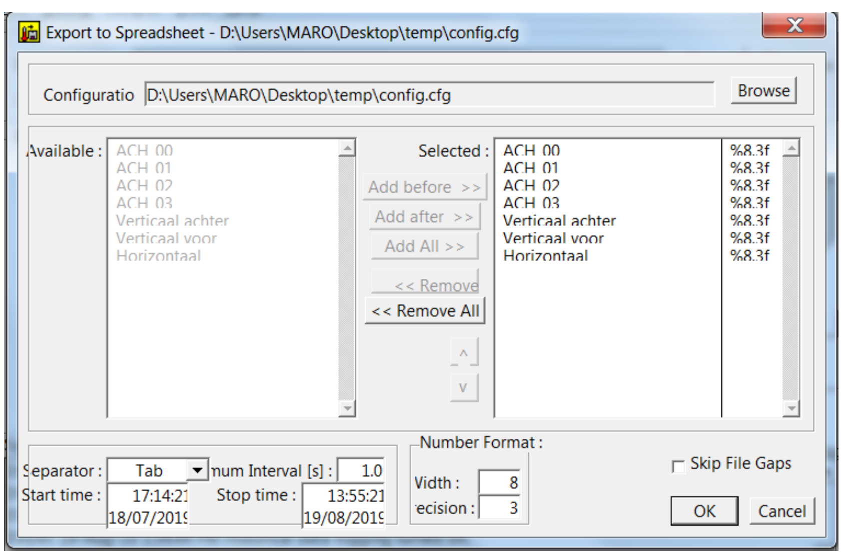

Figure 3.9: Export sheet in datalogger

Inside the jet trenching folder that is available at Boskalis R&D general, a small video named "*file export*" is available that shows how this is correctly been done.

Tips:

- As mentioned before make sure that you make a new folder for every test and save as the config file in there. If the export of the data goes wrong it is easy to find recover.
- If making a new folder every time the start time and stop time should automatically be corrected.

Step 7

If the data is correctly saved then the water can be drained, the hose can be disconnected and the top frame can be lifted. Advised is to lift the top frame slightly and then disconnect the hose, this method gives you more space to work. Before disconnecting the hose make sure that the electro motor is unplugged because the hose can be under an small electrical charge. Once the hose is disconnected place the top frame back and put the plough back to the beginning position for the next test. When putting the plough back to the beginning position watch that the cables hanging behind the cart are not in the way of the guide cart.

Once the plough is back at the beginning position the top frame can be lifted of and stored at the correct place. Next the clay holder can be lifted out of the holding tank and moved to the preparation area. Then make measurements and pictures from the results of the test.

In the report of M. Roos, W van Gurp and G Kemperman there are examples of how to process the data that is acquired from the test.

When the data is gathered from the test a new test can be prepared.

Tips:

- When disconnecting the hose put the bolts in a small cup of water, this way the clay on the bolts will not harden and the nut can be screwed easier on the bolt.

Risks:

- Unplug all electricity once your operating the crane and when you are working in the water.

4. Summary Risks & Tips

Step 1

Tips:

- Use packaging foil between the clay and the clay box, this makes removing the clay afterwards easier.
- Use a small wooden plank to make the top of the clay box flat, this is the easiest and fastest way.
- When not using the carpenters square and steel wire, put them in a bucket of water so it's wet and less clay will stick on to it.
- Push the straps used to lift the clay box in it's position under the clay holder. Once the box is in position it's hard to get the stress out of there.

Risks:

- Make sure that the straps are firmly put under the clay box. If they are not correctly put under the clay box, they could float once the holding tank is filled with water and could entangle in the plough.

Step 2

Tips:

- To minimize the risk during this step go slow and double check everything.

Step 3

Tips:

- Use a socket wrench and a normal wrench (size 10), this makes it easier to tighten the bolts in the limited space inside of the holding tank.
- Put the bolts in a small cup of water in between tests, if not the sand/clay in the thread will become hard and it will be harder to tighten the bolt.
- Advised is to move the flow until the front of the clay box, to check if the plough doesn't hit the clay box.

Step 4

Tips:

- Try to have the same lab partner during all tests, this way you can go faster through all the tests and can save you a lot of time in the end.
- Take your time the first couple times to get familiar with the procedures.
- Inform your lab partner correctly so he is prepared on what could happen.
- Save a new "*config*" file in a different map every time this way if exporting the data from the datalogger goes wrong, then the data from the test is easier to find.

Risks

- From this test you are working with high pressured jets and electricity close to water, so make sure that everybody is wearing the required PPE.

Step 5

Tips:

- When operating with higher pressures on the jet, its advised to have something against the spilling of the water, so that no electric equipment becomes wet. There are some wooden planks made that fit in the holes of the guidance rail who prevent water from spilling. Figure 3.7 shows how the wooden planks have to be fitted.

Risks:

- Breaking of the electro cables when not correctly guided.
- With the movement of the guidance cart no movement in the water is allowed.
- Operating with high pressured jets brings dangers with it, and everybody should be informed about these risks.

Step 6

Tips:

- As mentioned before make sure that you make a new folder for every test and save as the config file in there. If the export of the data goes wrong it is easy to find recover.
- If making a new folder every time the start time and stop time should automatically be correct.

Step 7

Tips:

- When disconnecting the hose put the bolts in a small cup of water, this way the clay on the bolts will not harden and the nut can be easier be screwed on the bolt.

Risks:

- Unplug all electricity once your operating the crane and working in the water.