AquaSoli GmbH & Co. KG

Ingenieurgesellschaft für Geotechnik, Wasserbau und Deponiebau

Recalculation of Resistances from C100x55x15x3 to Hat piles 20x80x48x80x3 and recommendation of foundation based on conducted load tests

Project: Lochem II, 10 MWp Netherland

Revision A

Order Nr. 20-153

Solar-Konzept GmbH

Munich, June 18th 2020

This report contains 17 pages text and 7 pages with attachments.

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1 List of sources and cited literature

ID	Source/Author	Title
U1	Andert + Mackert	Dokumentation von Zugversuchen, Errichtung einer Fotovoltaik-Anlage, Lochem/2; Rev.01, 20.12.2019
U2	Mounting Systems	EN19-0158-02 Vgl Auflagerreaktionen_2020-06-16.pdfvia Email Alexandra Vahl June 17th 2020

2 Annexes

Annex L	Location of the test points
Annex E	Evaluation of the testvalues

3 Purpose

Solar-Konzept GmbH ordered AquaSoli GmbH & Co. KG (AquaSoli) to recalculate the resistances from C100x55x15x3 to Hat piles 20x80x48x80x3 for the project Lochem II, Netherland. In the following, the characteristic and design resistances from the report on conducted load tests by Andert + Mackert [U1] will be determined. In a further step, these determined resistances are converted to Hat piles from Mounting Systems.

4 General data about the project and structural system

Andert + Mackert carried out load tests at 21 locations on site (**Annex L**).
All information about the project, the subsoil and the determined resistances are based solely on site report by Andert + Mackert [U1].

4.1 Description of the subsoil

According to [U1] the subsoil is described as follows (**Table 1**):

The topsoil is silty sand with a stiff, humusy consistency and a depth of up to 1.0m (0.3-0.4m).
This layer is underlain by a layer of lightly silty to silty fine to medium sand in medium-dense layers.
In the area of points 3-4, there is a clayey, fine sandy silt layer (soft-stiff) at a depth of approx. 1.0 to 1.40m, which dams up the surface water. At the time of the tests, the surface layer in this area was therefore partly mushy in consistency and had a low bearing capacity.
In the surrounding drainage ditches, the water is approx. 0.5m below the top edge of the terrain.

Table 1 – Description of the soil [U1]

Schicht	Tiefe [m]	Bezeichnung
1	0-0,70..1,0	Fein-Mittelsand , schluffig , schwach , humos , steif , stellenweise breiig
2	0,70..1,0-0,90..1,40	Schluff , feinsandig , stellenweise tonig
3	0,80..1,0-2,0	Fein-Mittelsand , stellenweise schwach schluffig , stellenweise tonig , mitteldicht

The following soil properties shall be applied according to [U1]:

Table 2 – Soil properties acc. [U1]

Schicht	Tiefe [m]	Wichte cal γ [kN/m³]	Wichte u. Auftrieb cal γ' [kN/m³]	Reibungs-winkel cal ϕ' [°]	Kohäsion cal c' [kN/m²]
1	0-0,70..1,0	18,0	8,0	32,5	5,0
2	0,70..1,0-0,90..1,40	19,5	9,5	30,0	10,0
3	0,80..1,0-2,0	19,5	9,5	35,0	0,0

Ramming obstructions are not mentioned in the report [U1].

4.2 Structural system

According to [U2] a two row structural system (**Figure 1**) mounted on Hat piles is projected (**Figure 2**).

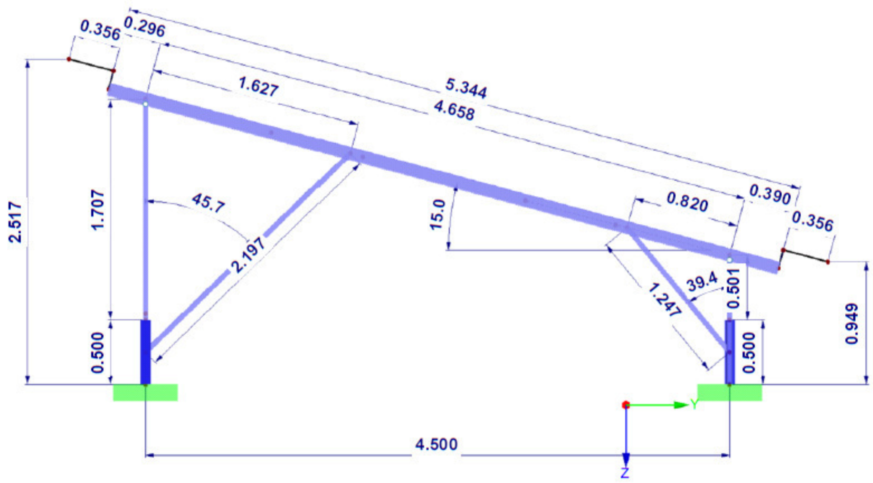

Figure 1 – projected mounting structure (EA)

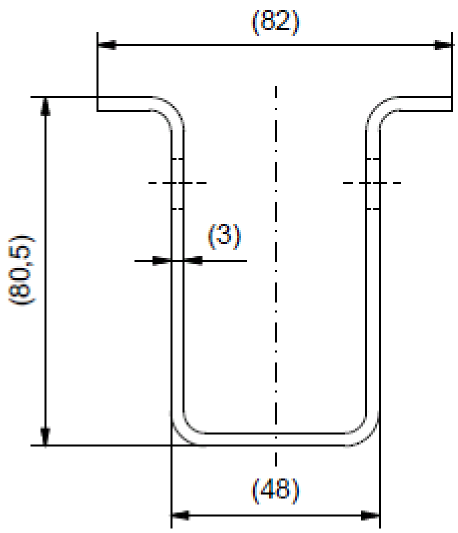

Figure 2 – projected Hat pile

The following structural loads are assumed for the structural system [U2]:

Table 3 – Design Loads on the structural system

	Design loads on the system [U2]				
System	Pile	Compression [kN]	Tension [kN]	Horizontal [kN]	Moment [kNm]
Edge Area	Front	11.87	1.11	6.00	1.47
	Rear	12.08	10.25	6.59	1.64
Field Area	Front	10.94	0	6.00	1.47
	Rear	11.25	5.55	6.05	1.47

5 Evaluation of the load tests

On November 12th 2019 tensile tests were carried out at 21 locations, compression tests at 2 locations and horizontal load tests at 3 locations. The location of the tests points can be seen in **Annex L**. C100x55x15x3 ramming piles were used for the tests. The piles were installed at a depth of 1.50m and 2.00m.
All piles had already been rammed several weeks before the tests.

From the documentation of the load tests [U1] the test results were recorded and evaluated according to EC7/NEN-EN 1997-1/NEN 9997-1. The evaluation can be seen in **Annex E.**
The following design resistances can be derived from the evaluation of the load tests:

Table 4 – Design Resistances C100x55x15x3 piles

	Design-Resistances			
Embedment depth [m]	Compression [kN]	Tension [kN]	Horizontal [kN]	Arm of lever [m
1.50	11.15	3.42	3.22	1.00
2.00	9.38*	5.13	3.36	1.00

* no critical load was achieved. Therefore the resistance from ED=1.50m can be taken for further consideration

6 Conversion of resistances to Hat pile

In order to calculate the resistances of the Hat pile on basis of the test results with C100x55 piles, following dimensions have been used:

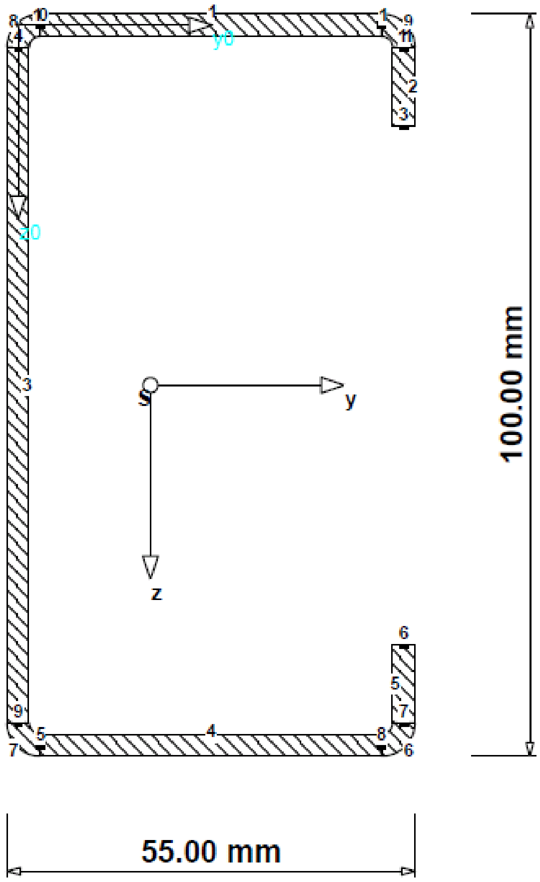

Figure 3 – Dimension of the tested ramming C100x55 pile

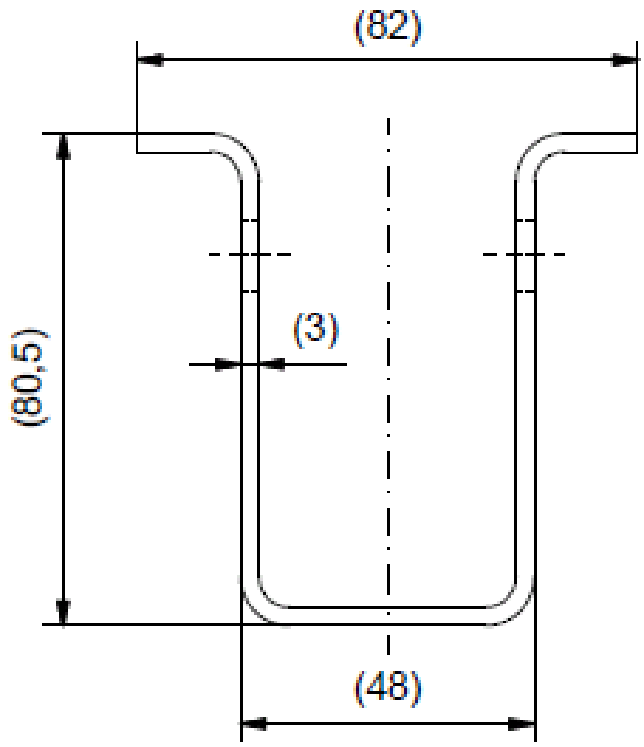

Figure 4 – Dimension of the projected Hat pile

<u>Axial tension direction:</u>

In axial tension direction only the skin friction of the piles causes the resistances. **Figure 5** and **Figure 6** show the cross sections of the skin area for the different piles.

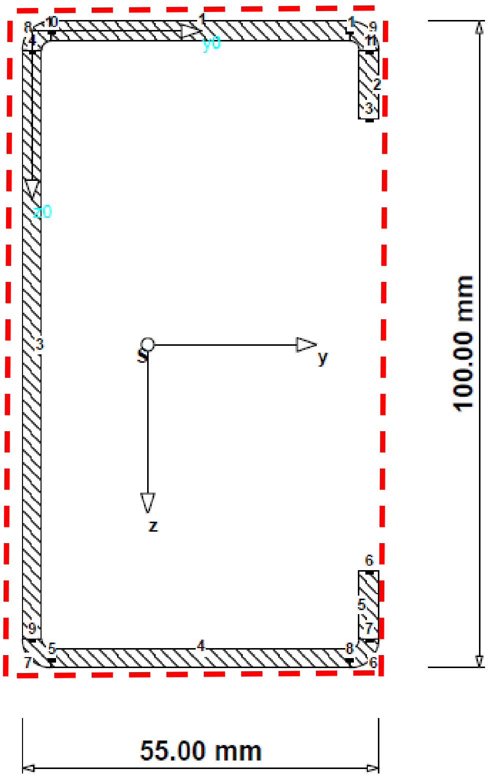

Figure 5 – Area of skin fiction of C100x55 pile

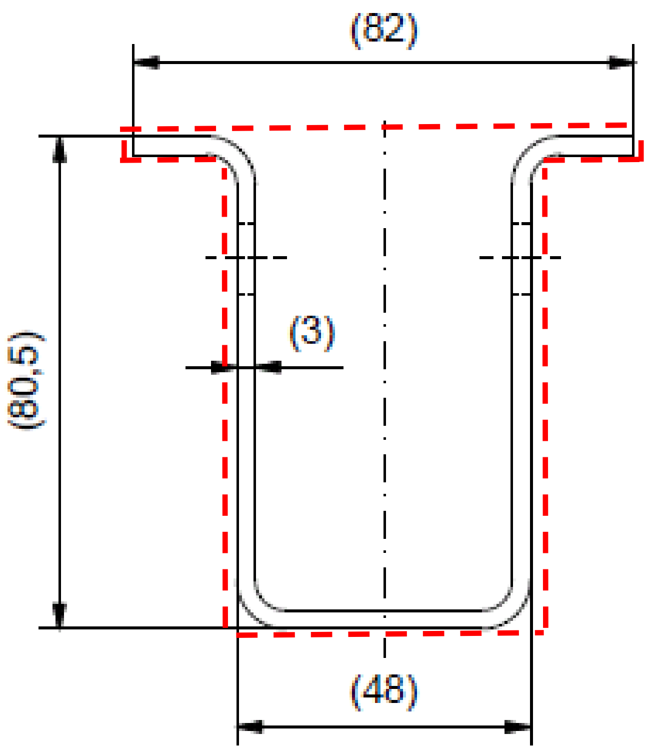

Figure 6 – Area of the skin fiction of Hat pile

U_{C100} = 2 x 10.0 + 2 x 5.5 = 31.00 cm

U_{Hat} = 2 x 8.2 + 2 x 8.05 = 32.50 cm

➔ Factor for recalculation 32.50 / 31.00 = 1.048

Table 5 – Recalculated axial tension resistance for the Hat pile

Embedment depth [m]	Design Resistance [kN]	
	C100x55	Hat Pile
1.50	3.42	3.58
2.00	5.13	5.37

Axial compression direction:

The resistances in axial compression direction are the combination of the skin friction and end bearing. The skin friction is the same as for axial tension resistance. The end bearing depends on the area of the tip.

Following areas of the tip have been used for the calculations:

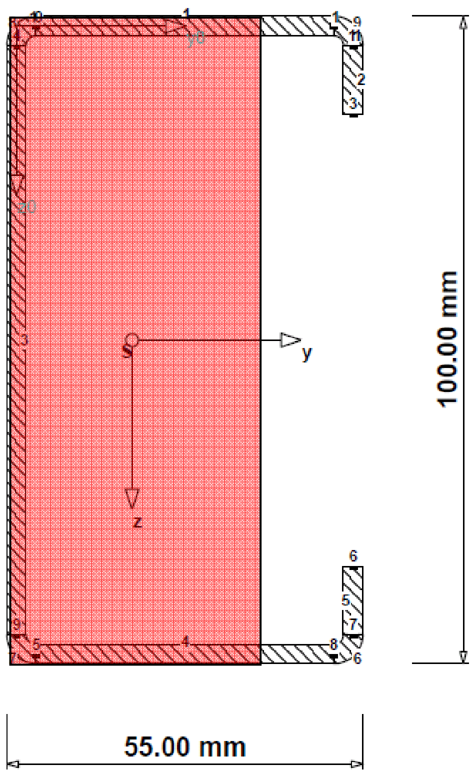

Figure 7 – Area of tip of C100x55

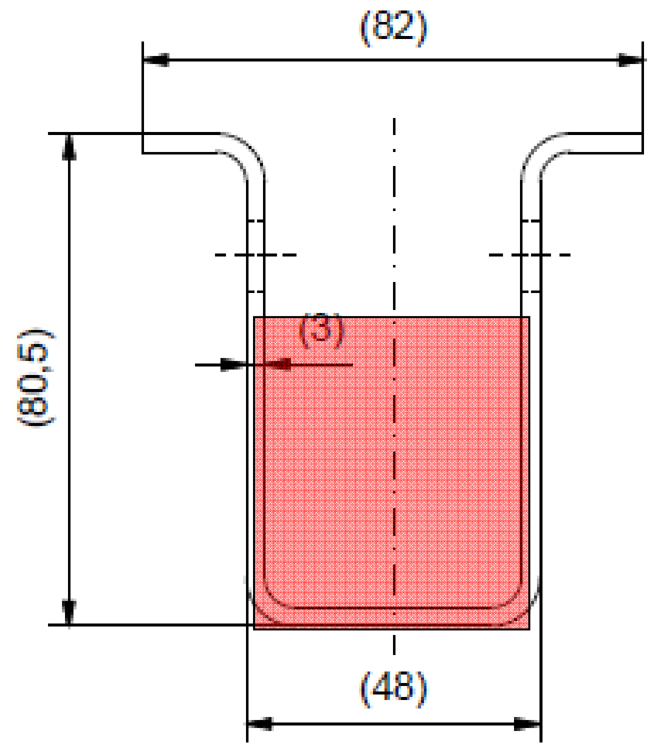

Figure 8 – Area of tip of Hat pile

A_{C100}= 100.0 x 55 x 2/3 = 3666.6 mm²

A_{CHat}= 48.0 x 80.5 x 2/3 = 2576 mm²

→ Factor of recalculation 2576/3666.6 = 0.70

The design tip compression resistances of the C-100 pile can be determined as

$R_{tp;d}$=$R_{c;d}$ – $R_{t;d}$

Table 6 – Recalculated axial compression resistance for the Hat pile

Embedment depth [m]	**Design Resistance [kN]**	
	C100x55	Hat Pile
1.50	11.15	8.99
2.00	9.38*	10.78

* no critical load was achieved. Therefore the resistance from ED=1.50m can be taken for further consideration

Horizontal tension direction:

In horizontal tension direction the recalculation was made with the program GGU – Latpile. Therefore with the results from the test diagrams the soil parameters were adjusted.

Following cross section values were used:

Table 7 – Cross section values of the piles

Type of profile	Cross section area A [cm²]	Iy [cm⁴]	Wel,y [cm³]	Width of the resistance side [cm]
C-100	6.68	106.72	21.34	5.5
Hat pile	6.82	55.16	14.27	8.2

Figure 9 shows the calibration of the soil model with the results of test pile 2H with a ramming depth of ED=1.50m.

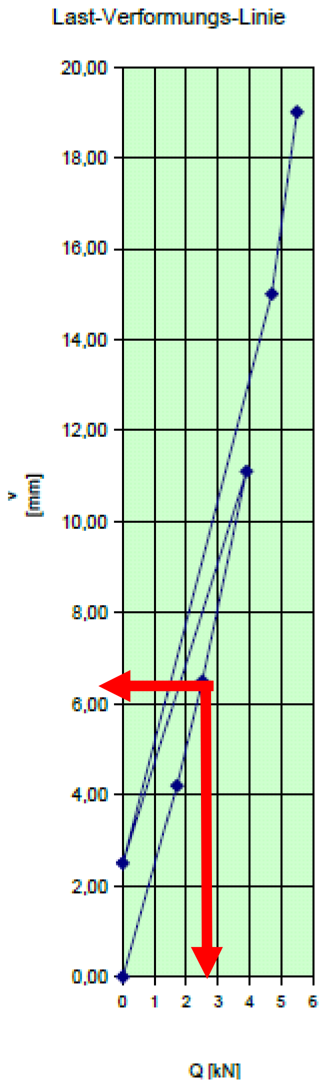

Figure 9 – test diagram with an installation depth of ED = 1.50m for the horizontal test of the test pile 2H

Out of **Figure 9** a plastic and elastic deformation of about 6.5 mm was reached with a horizontal load of 2.5 kN and an arm of lever of 1.00 m (➔ moment = 2.5 kNm).

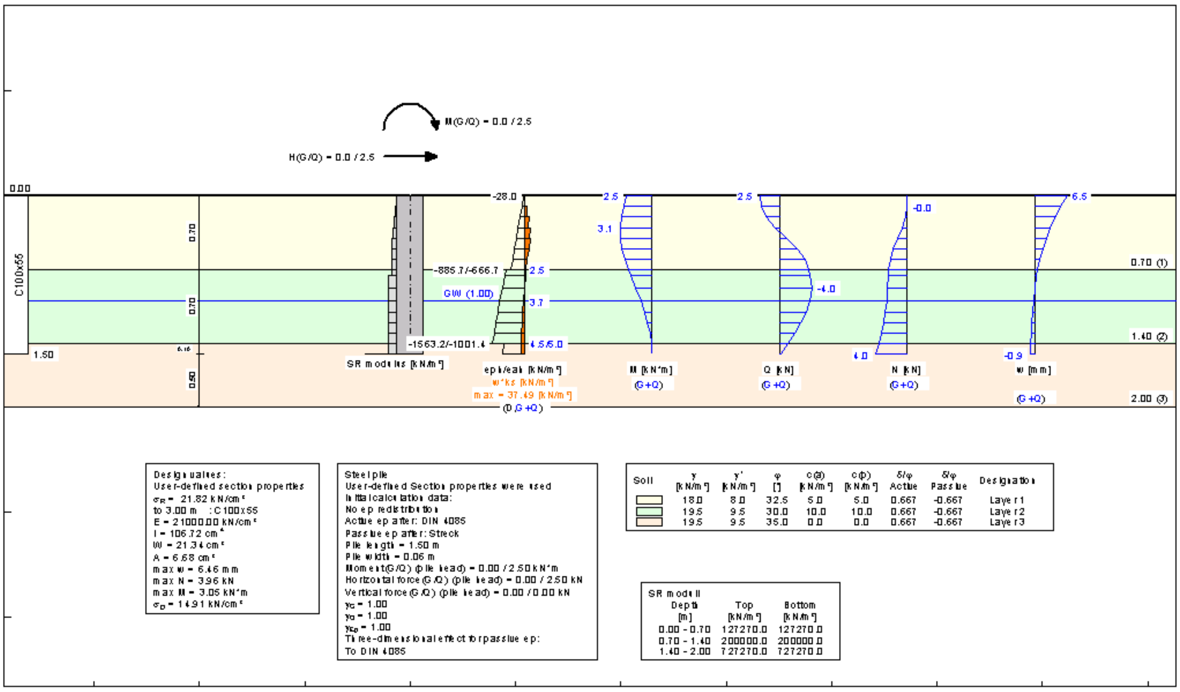

Figure 10– calibration of the soil material with the C100 pile ED=1.50m

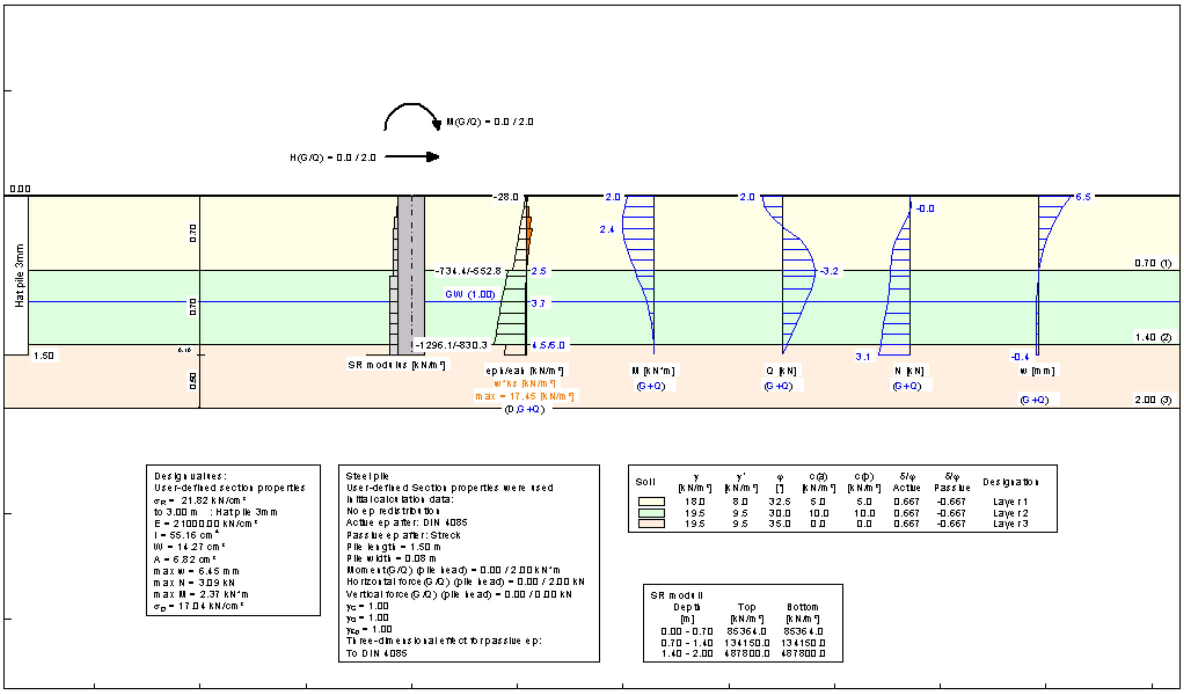

Figure 11 – recalculation of the resistances with Hat pile ED=1.50m

Out of the results given in **Figure 10** and **Figure 11** the following correlation factors for the horizontal resistances can be derived:

Table 8 – Correlation factors Hatpile/C100

Ramming depth [m]	Correlation factors Hat/C100
1.50	0.80

Table 9 – Recalculated horizontal tension resistances of the Hatpile in relation to C100

Ramming depth [m]	Design resistances in horizontal tension direction [kN] (arm of lever 1.0m)	
	C100	Hatpile
1.50	3.22	2.58
2.00	3.36	2.58

7 Conclusion, final notes and summary

A summary of the recalculated resistances can be found in **Table 10** In order to find a sufficient foundation the design resistances in **Table 10** have to be compared with the design loads in **Table 3**.

A utilization ratio of $\mu \leq 1.0$ has to be achieved (μ = design load/ design resistance).

Table 10 – Design resistances of recalculated Hat pile

Installation depth [m]	Axial com-pression [kN]	Axial tension [kN]	Horizontal [kN] Arm of lever 1.00m
1.50	8.99	3.58	2.58
2.00	10.78	5.37	2.58

Recommendation for the foundation with Hat piles:

- Edge Area:

Frontpile
Hat pile (**Figure 2**) with minimum embedment depth ED= 2.40 m

ED=2.40m EXTRAPOLATED
Type of pile:

Impacts on the foundation acc. to stat. Calculation				Design Resistance [kN]	Utilisation ratio [1]	Recommended abbreviation of axial distance [1]
charactistical load [kN]		design load [kN]				
$E_{C,k}$		$E_{C,d}$	11,87	12,2	0,972	-
$E_{T,k}$		$E_{T,d}$	1,11	6,8	0,163	-
$E_{H,k}$		$E_{H,d}$	6,00	6,2	0,975	-
M_k		M_d	1,47			
		Arm of lever h [m]:	0,25			

Rearpile

Hat pile (**Figure 2**) with minimum embedment depth ED= 3.20 m

ED=3.20m EXTRAPOLATED
Type of pile: Hatpile

Impacts on the foundation acc. to stat. Calculation				Design Resistance [kN]	Utilisation ratio [1]	Recommended abbreviation of axial distance [1]
charactistical load [kN]		design load [kN]				
$E_{C,k}$		$E_{C,d}$	12,08	15,1	0,801	-
$E_{T,k}$		$E_{T,d}$	9,56	9,7	0,989	-
$E_{H,k}$		$E_{H,d}$	5,70	6,1	0,933	-
M_k		M_d	1,42			
		Arm of lever h [m]:	0,25			

- Field Area:

Frontpile
Hat pile (**Figure 2**) with minimum embedment depth ED= 2.10 m

ED=2.10m EXTRAPOLATED
Type of pile: Hatpile

Impacts on the foundation acc. to stat. Calculation				Design Resistance [kN]	Utilisation ratio [1]	Recommended abbreviation of axial distance [1]
charactistical load [kN]		design load [kN]				
$E_{C,k}$		$E_{C,d}$	10,94	11,1	0,982	-
$E_{T,k}$		$E_{T,d}$	0,00	5,7	0,000	-
$E_{H,k}$		$E_{H,d}$	5,18	6,3	0,821	-
M_k		M_d	1,20			
		Arm of lever h [m]:	0,23			

Rearpile

Hat pile (**Figure 2**) with minimum embedment depth ED= 2.20 m

ED=2.20m EXTRAPOLATED
Type of pile: Hatpile

Impacts on the foundation acc. to stat. Calculation				Design Resistance [kN]	Utilisation ratio [1]	Recommended abbreviation of axial distance [1]
charactistical load [kN]		design load [kN]				
$E_{C,k}$		$E_{C,d}$	11,25	11,5	0,979	-
$E_{T,k}$		$E_{T,d}$	5,55	6,1	0,912	-
$E_{H,k}$		$E_{H,d}$	6,05	6,2	0,979	-
M_k		M_d	1,47			
		Arm of lever h [m]:	0,24			

Further notes:

- AquaSoli was not on site at any time. So AquaSoli cannot check the accuracy of the data. All calculations and assumptions are based solely on [U1]
- The resistances have been calculated on basis of C100 posts. The feasibility of pile driving for the new piles couldn't be determined.

We thank you very much for your confidence
and remain at your disposal, yours sincerely,

Munich, June 18th 2020

AquaSoli GmbH & Co. KG

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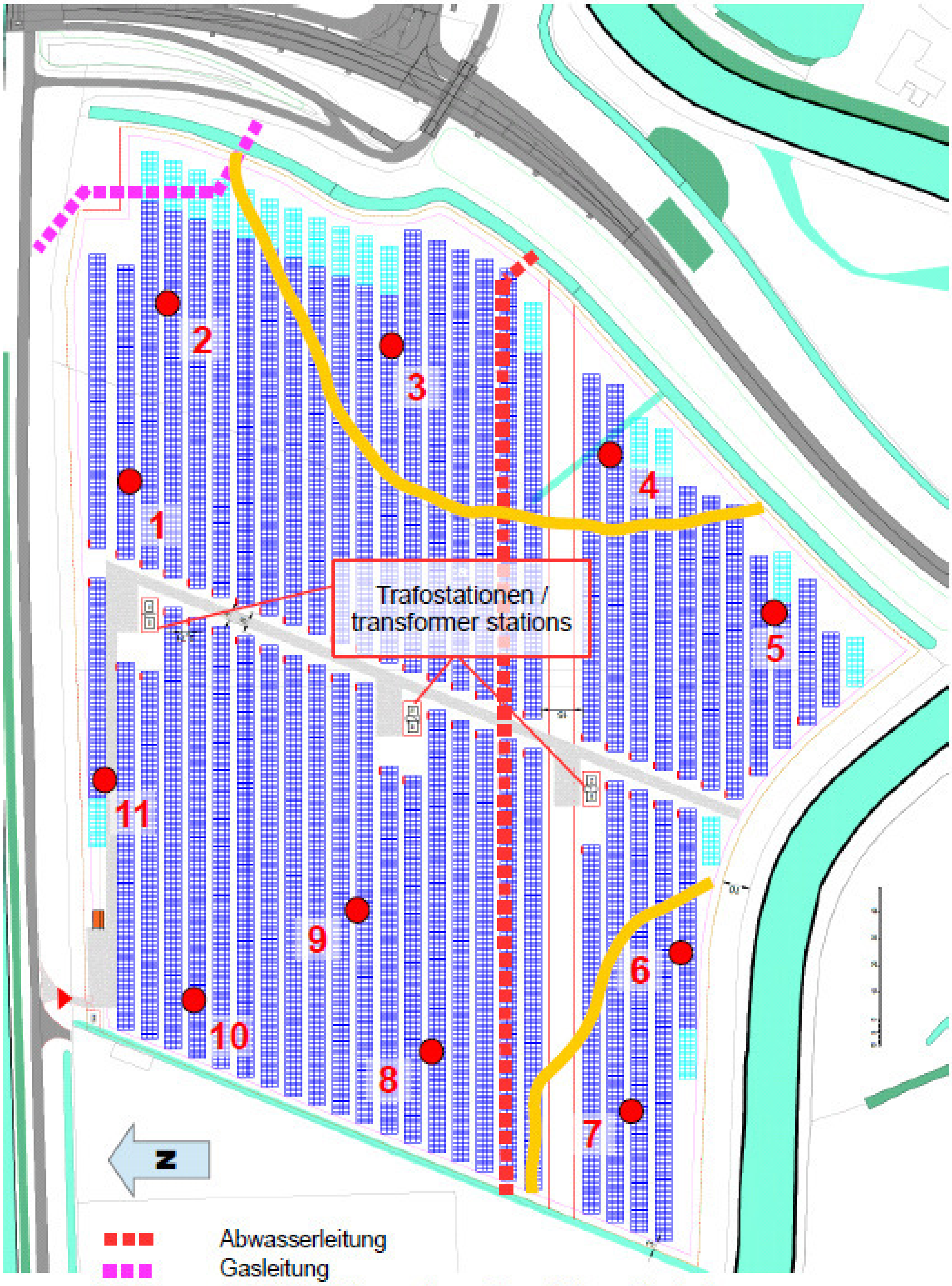
Annex L: Location of the test points



Abwasserleitung
Gasleitung
Bereiche mit besonders aufgeweichtem Oberboden

Derivation of the critical load regarding axial pressure forces at design level

Type of pile: C100x55 **Embedment Depth [m]:** 1,50

Critical/ maximum Load in axial compression direction [kN]
16,90

16,90	*$(R_{c;m})_{max}$*
16,90	*$(R_{c;m})_{mean}$*
16,90	*$(R_{c;m})_{min}$*
1	*N*
1,26	Xi_1:
1,26	Xi_2:
$(R_{c;m})_{mean} / \xi_1$:	*13,37*
$(R_{c;m})_{min} / \xi_2$:	*13,37*

Assuming a sound load distribution within the mounting structure the following caracteristical resistance acc. to EC7/ NEN-EN 1997-1can be derived from:

$R_{c;k}$ [kN]= 13,37

Safety factor on site of resistance acc. to EC7/ NEN-EN 1997-1:

γ_t= 1,2

Assuming a sound load distribution within the mounting structure the following design resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{c;d}$ [kN]= 11,15

Further Remarks:

Derivation of the critical load regarding axial pressure forces at design level

Type of pile: C100x55 **Embedment Depth [m]:** 2,00

Critical/ maximum Load in axial compression direction [kN]
13,50

13,50	*$(R_{c;m})_{max}$*
13,50	*$(R_{c;m})_{mean}$*
13,50	*$(R_{c;m})_{min}$*
2	*N*
1,20	Xi_1:
0,96	Xi_2:
$(R_{c;m})_{mean} / \xi_1$:	*11,25*
$(R_{c;m})_{min} / \xi_2$:	*14,06*

Assuming a sound load distribution within the mounting structure the following caracteristical resistance acc. to EC7/ NEN-EN 1997-1can be derived from:

$R_{c;k}$ [kN]= 11,25

Safety factor on site of resistance acc. to EC7/ NEN-EN 1997-1:

γ_t= 1,2

Assuming a sound load distribution within the mounting structure the following design resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{c;d}$ [kN]= 9,38

Further Remarks:

Derivation of the critical load regarding axial tension forces at design level

Type of pile: C100x55 **Embedment Depth [m]:** 1,50

Critical/ maximum Load in axial pullout/ tension direction [kN]
6,50
4,20
5,30
4,60
7,00
6,30
7,00
4,50
8,20
6,50

8,20	$(R_{t;m})_{max}$
6,01	$(R_{t;m})_{mean}$
4,20	$(R_{t;m})_{min}$
10	*N*
1,14	Xi_1:
0,91	Xi_2:
$(R_{t;m})_{mean} / \xi_1$:	*5,29*
$(R_{t;m})_{min} / \xi_2$:	*4,62*

Assuming a sound load distribution within the mounting structure the following caracteristical resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{t;k}$ [kN]= 4,62

Safety factor on site of resistance acc. to EC7/ NEN-EN 1997-1:

$\gamma_{s,t}$= 1,35

Assuming a sound load distribution within the mounting structure the following design resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{t;d}$ [kN]= 3,42

Further Remarks:

Derivation of the critical load regarding axial tension forces at design level

Type of pile: C100x55 **Embedment Depth [m]:** 2,00

Critical/ maximum Load in axial pullout/ tension direction [kN]
7,30
15,00
6,70
7,50
6,30
11,50
6,50
7,50
12,00
9,00

15,00	*$(R_{t;m})_{max}$*
8,93	*$(R_{t;m})_{mean}$*
6,30	*$(R_{t;m})_{min}$*
10	*N*
1,14	Xi_1:
0,91	Xi_2:
$(R_{t;m})_{mean} / \xi_1$:	*7,86*
$(R_{t;m})_{min} / \xi_2$:	*6,93*

Assuming a sound load distribution within the mounting structure the following caracteristical resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{t;k}$ [kN]= 6,93

Safety factor on site of resistance acc. to EC7/ NEN-EN 1997-1:

$\gamma_{s,t}$= 1,35

Assuming a sound load distribution within the mounting structure the following design resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{t;d}$ [kN]= 5,13

Further Remarks:

Derivation of the critical load regarding horizontal tension forces at design level

Type of pile: C100x55 **Embedment Depth [m]:** 1,50

Critical/ maximum Load in horizontal tension direction [kN]
5,50

5,50	$(R_{tr;m})_{max}$
5,50	$(R_{tr;m})_{mean}$
5,50	$(R_{tr;m})_{min}$
1	*N*
1,26	Xi_1:
1,26	Xi_2:
$(R_{tr;m})_{mean} / \xi_1$:	*4,35*
$(R_{tr;m})_{min} / \xi_2$:	*4,35*

Assuming a sound load distribution within the mounting structure the following caracteristical resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{H;k}$ [kN]= 4,35

Safety factor on site of resistance acc. to EC7/ NEN-EN 1997-1:

$\gamma_{s,t}$= 1,35

Assuming a sound load distribution within the mounting structure the following design resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{H;d}$ [kN]= 3,22

Further Remarks:

Derivation of the critical load regarding horizontal tension forces at design level

Type of pile: C100x55 **Embedment Depth [m]:** 2,00

Critical/ maximum Load in horizontal tension direction [kN]
5,90
4,70
5,50

5,90	$(R_{tr;m})_{max}$
5,37	$(R_{tr;m})_{mean}$
4,70	$(R_{tr;m})_{min}$
3	*N*
1,18	Xi_1:
0,94	Xi_2:
$(R_{tr;m})_{mean} / \xi_1$:	*4,54*
$(R_{tr;m})_{min} / \xi_2$:	*5,00*

Assuming a sound load distribution within the mounting structure the following caracteristical resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{H;k}$ [kN]= 4,54

Safety factor on site of resistance acc. to EC7/ NEN-EN 1997-1:

$\gamma_{s,t}$= 1,35

Assuming a sound load distribution within the mounting structure the following design resistance acc. to EC7/ NEN-EN 1997-1 can be derived from:

$R_{H;d}$ [kN]= 3,36

Further Remarks: